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GAS AMPLIFICATION OF PHOTO-ELECTRIC CURRENTS FOR HIGH VALUES OF E/P

NEIL EDWARD HANDEL[1]

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INTRODUCTION

The fundamental phenomenon of ionization of atoms by electron impact is described in every elementary physics textbook and is, in general terms, familiar to every one. It is operating whenever potential is applied to a gas discharge device of any kind and an electric current passes. In neon signs, mercury vapor rectifiers, grid glow tubes and the like, the conditions that exist are extremely complicated and hence, ever since the earliest investigations, attempts have been made to analyze the behavior of such devices in terms of some simpler, fundamental phenomena. One of the most fruitful attempts was the introduction by Townsend (1) of the so-called "ionization coefficients" which measure the rate of ion production under the simplest possible conditions, namely, by electrons in an extensive, uniform field.

According to Townsend, an electron first gains energy from the field and then loses it by colliding with a gas atom to form an ion, and he denotes by α the number of ions produced by an electron in traveling one centimeter in the direction of the field. Townsend made the first measurements of α in 1900 and studied

[1] Acknowledgments: I wish to express my gratitude to Dr. C. K. Stedman for suggesting this problem and assisting me in carrying out the investigations.

its dependence upon the field strength E and the pressure P. He determined that α could be expressed as a function of E/P and established the custom of plotting the quantity α/P as a function of the single independent variable E/P. Many others have since followed up the work of Townsend, improving upon his technique, extending the range of investigation, and making use of gases of greater purity. Paralleling the experimental studies of α there have been persistent attempts to calculate its magnitude theoretically from the known properties of atoms and electrons.

In the past all measurements of α/P have been in a range of E/P from 20 to 2000 volts/cm-mm Hg in air and from 10 to 3000 volts/cm-mm Hg in certain other gases. All curves show a tendency to approach a maximum value of α/P, but no reliable data show an actual peak followed by a decline. One purpose of the present experiment was to extend this range and measure α/P for air at high values of E/P. A further purpose was to determine whether the very complicated theory required to calculate α at low E/P would become less involved at high E/P.

THEORY

A. Ionization by Collision

Consider two plane, parallel electrodes immersed in a gas with a potential applied between them. As the result of irradiation with ultra violet light the cathode emits N_o electrons per second which are accelerated by the field. These electrons collide with neutral gas atoms and, according to the fundamental hypothesis of Townsend, produce α ions per centimeter of travel in the direction of the field. For every positive ion produced, another electron is liberated which also proceeds to gain energy from the field and ionize gas atoms. If N is the number of electrons crossing a plane at a distance X from the cathode in unit time, then the increase in this number in a distance dx is given by

$$dN = \alpha N\, dx \tag{1}$$

Upon integration this becomes

$$N = N_0 \epsilon^{\alpha d} \tag{2}$$

The total current is necessarily the same across any plane perpendicular to the field and at the anode ($X = d$) all of the current is carried by electrons. Therefore

$$I = N_0 e \epsilon^{\alpha d} = I_0 \epsilon^{\alpha d} \tag{3}$$

where I is the total current through the space and I_o is the primary photo-electric current at the cathode.

This equation is the basis of the experimental method of determining α, using a tube which is so constructed that the spacing of the plates is variable. The current I is measured as a function of spacing d, and $\log_e I$ is plotted against d. If the resulting curve is a straight line, Townsend's hypothesis is confirmed and the slope of the line is numerically equal to α, the number of ion pairs produced per centimeter per electron. In a later chapter, data obtained by this method will be presented.

B. Theoretical Determination of α

Townsend's somewhat idealized concept of ionization by electrons drifting in a uniform field has been a valuable aid in analyzing the more complicated conditions existing in most discharges. Nevertheless, the conditions which exist in the Townsend apparatus itself are by no means simple. When an electron collides with a normal gas atom there is not a certainty, but only a possibility, that an ion will be produced. The probability depends on the energy of the electron, being zero for electron energies less than the ionization potential of the gas, and varying more or less rapidly at higher energies, as illustrated in Figure 1. In addition, an electron can excite normal gas atoms to any one of a large number of excited states, the probability for each state being again a function of electron energy. With these facts in mind, the paths of a group of electrons starting at the cathode may be visualized.

Initially, the photoelectrons have very little energy, but as the electric field accelerates them toward the anode their velocity increases. Their first collisions with gas atoms take place at energies well below any critical potentials and are, therefore, elastic. Moreover, since the mass of the electrons is much

smaller than that of the atoms, the lighter particles will rebound with practically no loss of energy, and in random directions. Due to the acceleration by the electric field, succeeding free flights will have some curvature in the field direction, and the electrons constantly gain energy. After each impact the velocity is randomly directed but always increasing in magnitude, and the electron has a small resultant drift in the field direction. After a short time, many of the electrons gain sufficient energy to be able to excite or ionize. From this point on, each collision offers the possibility of exciting or ionizing an atom with the consequent loss of electron energy. The probability of ionization becomes greater as electron energies increase above the ionization potential so that soon most of the electrons have experienced inelastic impacts and have lost a large part or all

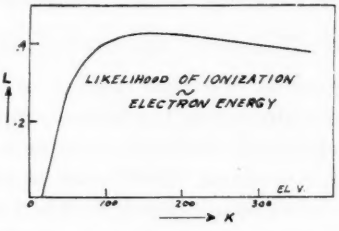

FIG. 1. Curve of Likelihood of Ionization as a Function of Electron Energy

of the energy they gained from the field. The whole process will repeat itself with an electron making elastic collisions resulting in zigzag paths until enough energy is gained and another inelastic impact occurs leaving the electron once more with reduced energy. Thus most of the electrons will soon attain a maximum average energy associated with a certain drift speed in the field direction, which is superimposed upon the random paths. This terminal drift speed is just enough to allow them to gain energy from the field at the same rate it is being lost in inelastic collisions.

The above picture of the conditions in a Townsend discharge holds at low values of E/P. In this range considerable success has been achieved in calculating α theoretically by a method which can be outlined as follows: If α is the number of ion pairs

created per centimeter of travel in the direction of the field by an electron whose drift velocity in the field direction is v cm. per second, then αv is the number of new electrons created per second. The drift velocity is given by $v = K_e E$ where K_e is the electron mobility constant and E is the field strength. K_e has recently been evaluated by Bradbury and Nielsen (2) for a number of pure gases. Besides having the drift velocity v, the same electron is covering a zigzag path at a velocity C cm per second. However, if this random velocity C is such that the electron energy is above the ionizing potential, then a certain probability of ionization, P_i exists. This quantity can be evaluated as an absorbing cross-section by measurements of the Compton-Van Voorhis or Smith (3) type. If $P_i(C)$ is the number of ions made per centimeter of random motion in a gas at 1 mm pressure then at p mm pressure an electron of random velocity C will make $pCP_i(C)$ ions per second. To find the chance of an electron having a velocity C we must calculate $f(C)\,dc$, the velocity distribution law for electrons in a gas at a given E/P. Smit (4) has accomplished this for He and it can undoubtedly be done for other gases. It must be remembered that $f(C)\,dc$ is a function of E/P. Now if $pCP_i(C)\ f(C)\,dc$ is integrated over all values of C from C_i (the velocity at which the electron energy is just equal to the ionization potential of the gas) to infinity we will obtain the expression for all the new ions created per second by one electron at a given E/P in the gas. This expression must also be equal to αv and hence

$$\alpha v = \alpha E K_e \frac{760}{p} = p \int_{c_i}^{\infty} CP_i(c) f(c)\, dc \tag{4}$$

so that

$$\alpha/p = \frac{1}{760 K_e \dfrac{E}{p}} \int_{c_i}^{\infty} CP_i(c) f(c)\, dc \tag{5}$$

In addition $\frac{1}{2}mc^2 = \dfrac{Ve}{300m}$ if V is in volts.

Hence $c = \sqrt{2e/300m}\ \sqrt{V}$

We can also express $P_i(C)$ as $P(V)$, and $f(C)\,dc$ as $F(V)\,dv$. Thus at a given E/P we have the relation

$$\alpha/p = \frac{\sqrt{\frac{2e}{300m}}}{760K_e\frac{E}{p}} \int_{e_i}^{\infty} P(V)V^{\frac{1}{2}}F(V)\,dv \tag{6}$$

Emmelius, Lunt, and Meek (5) have used this general method in calculating α/P for several small values of E/P for H_2, N_2, O_2, and A. The values they obtain do not agree very well with experimental values, and their main error seems to have been the use of a maxwellian distribution of electron energies. Druyvesteyn (6) in 1936 succeeded in calculating a distribution function for Ne and used it to evaluate α/P for E/P equal 5, 7.5, 10, 20, and 30 volts/cm-mm Hg. The values he obtained agree quite well with experiment. Thus the principal difficulty in attempting an accurate calculation of α/P as a function of E/P is the determination of the proper electron energy distribution function $F(V)\,dv$ for each gas. Since $F(V)\,dv$ is itself a function of E/P, it is seen that α/P will undoubtedly be a complicated function of E/P. Again it is well to point out that this theory has been applied only at low values of E/P. However, experimental data have been obtained over greatly extended ranges of E/P.

Although the fact has not been clearly pointed out in the literature, there is even good reason to suppose that as we proceed to higher values of E/P Townsend's concept of a constant rate of ion generation is not applicable, because the electrons cannot attain a terminal energy. The likelihood of ionization and excitation is found to be a function of electron energy. Therefore if the electrons were to gain energy at a rate greater than that required by the losses, a terminal energy would never be reached and the number of ion pairs produced per centimeter of travel in the field direction would vary from point to point. For example, in an experiment to be described later some measurements were made in the region of E/P equal 10,000 volts/cm-mm Hg with a pressure of .07 mm Hg and a field strength of 700 volts/cm. The measurements revealed that each electron was creating 0.6 ion pairs per centimeter of drift in the field direction which indicates that the distance between ionizing collisions was

about 1.7 cm. The electron mean free path is about .35 cm. at this pressure so there could not have been more than 6 or 7 impacts between ionizing collisions. In the space of 1.7 cm. an electron gains 1200 electron volts of energy which cannot possibly be dissipated, even supposing that at every one of these impacts an excited atom is produced. Therefore the electron energy is steadily increasing and there can be no constant rate of ion generation. Since at the highest values of E/P a terminal energy cannot be attained, whereas at low values of E/P one undoubtedly is attained, it is natural to inquire over what range of E/P a true α can exist. It is not possible to treat the whole problem quantitatively because such an analysis would be equivalent to a complete theory of α/P, which is only available at the lowest values of E/P. However, it is possible to make a qualitative analysis.

One method of forming an estimate is to calculate the average energy gained by an electron in a free flight and equate it to the maximum amount of energy which electrons can, on the average, conceivably dispose of by inelastic impacts. Thus if an electron starts a free flight with a speed v at an angle θ to the field, its velocity may be resolved into components $v \cos \theta$ parallel and $v \sin \theta$ at right angles to the field. The $v \sin \theta$ remains unchanged but during the time of free flight, the $v \cos \theta$ becomes $(v \cos \theta + a\tau)$ where a is the acceleration due to the electric field. The gain in kinetic energy K is given by

$$\Delta K = \frac{m}{2} (2a\tau V \operatorname{Cos} \theta + a^2\tau^2) \tag{7}$$

where τ is the average time of flight given by $\tau = l/\omega$ and l and ω are respectively the mean free path and the average velocity of the electron during a free flight. The acceleration a due to the field is given by $a = Ee/m$. If the distribution of electron velocities is truly random, the first term on the right will drop out in averaging over all possible directions and substituting for a and τ, the energy gain equation becomes

$$\Delta \bar{K} = \tfrac{1}{2}(Eel)^2/mw^2 = (Eel)^2/4\bar{K} \tag{8}$$

where $\bar{K}$ is the average energy.

This simple theory assumes a straight line path for the electron which we know is, in general, not possible if it is to gain energy from the field. However, if the gain of energy per path is small compared to the average energy of the electron, the path will approximate a straight line and the calculation is not greatly in error. The quantity *Eel* gives the amount of energy gained per free flight in the direction of the field. If we denote this by ϵ, then the expression for the average gain of energy per free flight in random directions becomes

$$\epsilon^2/4\bar{K} = \Delta\bar{K} \tag{9}$$

Now the greater part of the energy losses must be due to the production of excited atoms. Therefore, since we wish to set an upper limit for the energy losses, let us assume that the electrons have an average energy of 10 volts which is near the peak of the curves for likelihood of excitation. In addition, the likelihood of excitation at the peak of most excitation curves is of the order of one excitation for every 100 impacts. If, to be conservative, it is assumed that there might be a possibility of excitation at every tenth impact, then the gain per free flight could not be more than 1 volt. Thus the equation would become

$$\epsilon^2/4\bar{K} \leqq 1 \qquad \text{and} \qquad \bar{K} = 10$$

hence

$$\epsilon = \sqrt{40} = 6.3 \text{ volts/free path}$$

Since the electron mean free path at 1 mm pressure is about 2.5×10^{-2} cm., this average gain per free flight represents a value of E/P equal 252 volts/cm-mm Hg. The above is a very conservative estimate and there is a good possibility that the limit of terminal energies is reached at much lower values of E/P.

Another way of arriving at an estimate of the range of E/P in which a true α exists, makes use of experimental data. Figure 2 illustrates a typical experimental curve of α/P vs E/P for air as given by Engel and Steenbeck. Since E is the energy gained by the electron per centimeter of travel in the field direction, and α is the number of ions produced in the same distance, it

follows that the quantity E/α expresses in electron volts the energy used in producing one ion. E/α as determined from Figure 2 is plotted as a function of E/P in Figure 3. In general this quantity greatly exceeds the ionization potential of the gas and if a terminal energy is to exist, we must account for the excess by ascribing it to losses by excitations. These losses can be estimated and whenever the excess energy per ion becomes

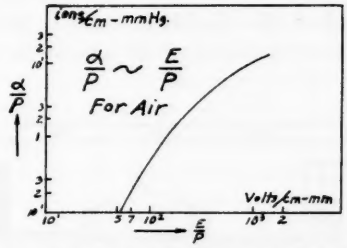

FIG. 2. Curve of α/P as a Function of E/P

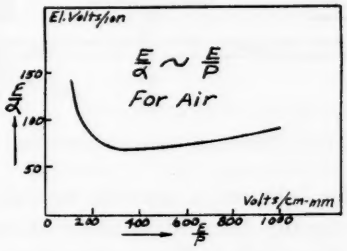

FIG. 3. Curve of E/α as a Function of E/P

too large to be accounted for in this manner, we conclude that electron energies are continuously increasing, a terminal energy is not reached and a true α does not exist.

APPARATUS AND PROCEDURE

One purpose of the present investigation was to measure α at high field strength and low pressures. The design of the tube and associated apparatus used in these measurements is described in the following paragraphs. For the measurement of α by the

method outlined on page 141 it was necessary that the discharge occur only in a uniform field, that the cathode be illuminated with ultra violet light, preferably entering the tube at an angle normal to the surface of the cathode, and finally it was necessary that the spacing of the plates be variable. In addition some of the features were determined by the desire to measure sparking potentials with the same tube, and will be discussed in a later section.

The final model of the discharge tube is shown in Figure 4. Essentially the tube consists of an anode *A* capable of trans-

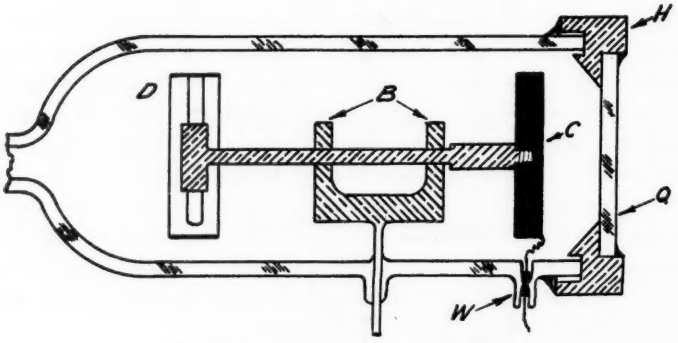

FIG. 4. Discharge Tube Cross-section

mitting ultra violet light and a movable cathode *C*. Heretofore the cathode has usually been illuminated through perforations or narrow slits in the anode. The transmission of such an anode cannot be more than a few percent or the field will be too much distorted by the holes. The anode in the present tube was a quartz plate upon which had been sputtered a very thin, electrically conducting gold film. Even though the film was so thin that the visible light transmitted was a light hazy green, the electrical conductivity was high to all parts of the surface. Such thin gold films have been found by F. Goos (7) to transmit as high as 70% of the incident ultra violet radiation in the region of the 2536 angstrom line of Hg. The high optical conductivity and the fact that the gold film constitutes a continuous, electrically conducting surface obviating any distortion of the field

make this an ideal method for introducing the necessary ultra violet excitation.

The circular quartz plate Q, 3.8 cm in diameter, was sealed in the steel head H with apiezon wax. The head itself was mounted on the end of the glass tube of about 4.6 cm diameter, by the use of picein wax. The cathode C was made of zinc foil glued on a circular piece of bakelite 2.8 cm in diameter. The bakelite in turn was mounted on a brass rod passing through two brass bearings B and was counterbalanced by a light iron drum D allowing the cathode to be moved by the action of a magnetic coil surrounding the tube. At first the cathode lead was brought out through the wax sealed side tube W. Later on the idea of measuring both α and sparking potentials with the same tube was discarded due to the troublesome leakage that developed over the comparatively short leakage paths on the inside surface. The cathode was then connected directly to the brass supporting rod so that the former cathode lead could be used to ground an inner conducting guard ring of aquadas painted on the inside surface of the tube between the anode and the cathode lead. A similar, grounded guard ring on the outside of the tube eliminated surface leekage.

The essential parts of the vacuum system such as the fore-pump, the diffusion pump, and the traps were rather conventional. However, several features of the system made it particularly adaptable to this type of work. Trouble with stopcocks was eliminated by the use of a mercury cut off C as shown in Figure 5. Once the system was evacuated and the mercury allowed to rise in the two arms, the pressure could be maintained at a constant value over long periods of time. The bubble trap B was necessary to prevent any bubbles from escaping into the system. Another feature of particular interest was the calibrated leak (8) L, consisting of a fine crack in a glass tube with a surrounding mercury column that normally sealed the system. When the mercury was lowered, air could be drawn into the system through the drying tube D and the leak. After the leakage of the crack was calibrated, it was quite easy to duplicate a pressure at will. The rate of the particular leak used was about 7 microns per second. Pressures were measured with a McLeod gauge de-

signed to have an open scale in the range of pressures used. The trap T_2 nearest the tube was necessary to prevent mercury

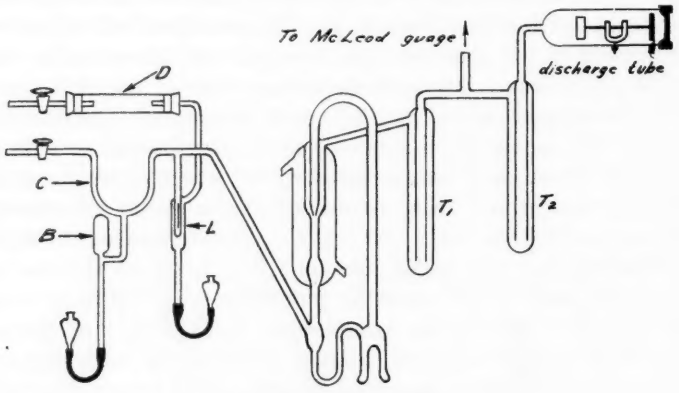

FIG. 5. Vacuum System

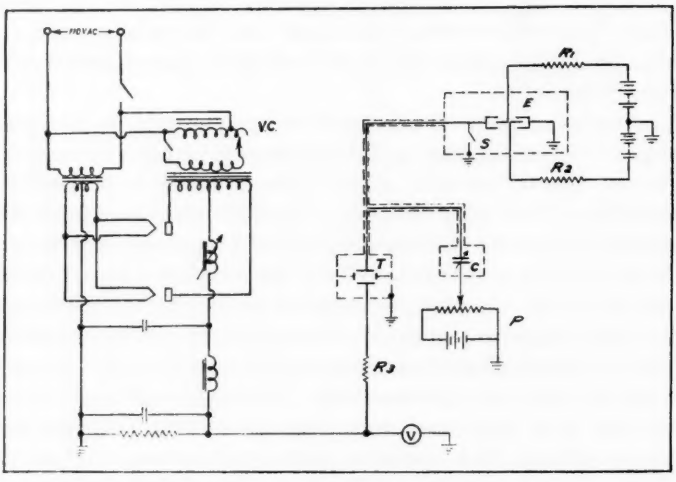

FIG. 6. HV Supply and Discharge Tube Circuit

vapor from entering the tube from the McLeod gauge and amalgamating with the gold film that formed the anode.

The measuring circuit is shown in Figure 6. It consisted of a

power supply capable of delivering potentials from 0 to 2000 volts, a Wien-Harms variable standard capacitor C of high leakage resistance and specially designed for electrometer measurements, a binant electrometer E, a shorting switch S, and a Leeds and Northrup Student Type potentiometer P. The electrometer is used only as a null point indicating device. Current through the tube charges the condenser and builds up a potential difference between the grounded and the ungrounded plates of the electrometer. An equal and opposite potential V is added in series by adjusting the potentiometer until the electrometer deflection is brought back to zero. The charge on the condenser is now given by $Q = CV$ and the anode is at ground potential. In practice the capacitor was allowed to charge for a given length of time and the potential across it at the end of that time was measured by the use of the potentiometer as explained above. If C was the capacity, T the time of charging, and V the potential built up across the capacitor, then the current I flowing through the tube is given by the equation

$$I = CV/T \tag{10}$$

This assumes, of course, that the current was constant throughout the period of charging, as will be the case if the pressure, applied voltage, and the ultra violet illumination are constant.

The problem of a suitable source of ultra violet was solved by the use of a bactericidal mercury vapor lamp manufactured by Westinghouse. Although this lamp was originally designed for *AC* operation it was found to give a more constant output when operated on *DC* where stabilizing batteries and resistances could be used as shown in Figure 7. To supply the filament with 8.5 amperes at 2 volts, a 6 volt storage battery was charged through dropping resistors from the 110 volt line at the same rate and the filament was supplied by additional dropping resistors from the battery. Due to the extremely low resistance of the storage battery compared to the resistance of the filament circuit, any change in the potential of the *DC* line would change the charging rate of the battery but leave the potential across the filament network practically constant. In a similar manner a 22 volt battery was used to stabilize the plate current supply

which furnished 2 amperes at 14 volts. Radiation from the source was collimated by two circular holes 0.8 cm in diameter and spaced 2 cm apart.

To obtain data, the *uv* source was first turned on and allowed to operate for three hours to become stable. The pressure was then set at the desired value. With the tube electrodes set at

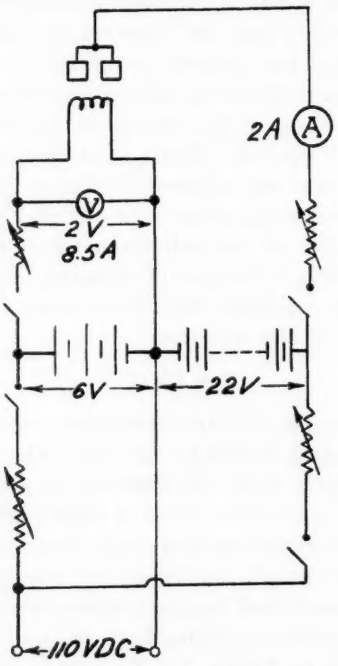

FIG. 7. UV Source and Stabilizing Circuit

maximum spacing, the radiation cut off by the shutter and the proper potential applied to the tube, the grounding switch was opened. The shutter was next opened and the condenser allowed to charge. At the end of two minutes the shutter was closed and the electrometer brought to zero by adjusting the potentiometer. From the potentiometer reading, the time, and the condenser capacity the current could be calculated by equa-

tion 10. The electrode spacing was then changed and read to within ± 0.005 mm by a traveling microscope. The accelerating voltage was adjusted to the proper value to maintain the original field strength and the above process was repeated. By plotting each point as it was observed, errors in reading and calculation were immediately checked. Readings of current I for five different values of d between 0.5 cm and 1.28 cm were obtained for each value of field strength. When log I was plotted as a function of d, a straight line resulted. The slope of the line was

TABLE 1

Data for Figures 9, 10, 11, 12

E/P	α/P	E/P	α/P
685	4.66	705	4.31
1370	5.36	1410	6.39
2778	5.69	2820	7.00
4167	6.64	4230	6.416
5555	7.39	5640	6.59
6944	5.84	7050	7.84
8333	8.89	8460	8.477
9722	7.88	9870	8.33
10958	7.88	11280	8.22
12330	5.53		
714	4.84	714	5.41
1428	5.33	1428	6.26
2856	8.64	2856	7.39
4284	6.66	4284	7.35
5700	7.57	5700	8.26
7140	12.56	7143	9.04
8580	8.74	8570	9.23
9800	7.31	10000	9.05
11400	7.70	11430	8.87

the value of α corresponding to the particular values of E and P used. In order to determine the value of α more accurately, the curves were reduced by the method of least squares (9). In this case the value of d was accurately known while the value of log I involved random errors due to the indirect method of measurement, hence the reduction involved rather simple calculations.

The data obtained by the method just described are presented

in Table 1 and Figures 8, 9, 10, 11, and 12. Figure 8 is a representative group of log I vs d curves. Only five of the usual set of nine obtained at one time are shown due to the fact that the slopes are all similar in magnitude and hence if all were plotted, the result would be confusing. Figures 9, 10, 11, 12 represent four curves of α/P plotted as a function of E/P over an extensive range. The interpretation of these data will be presented later.

INTERPRETATION OF DATA

It has already been shown that a constant rate of ion generation as conceived by Townsend cannot exist above $E/P = 250$ volts/

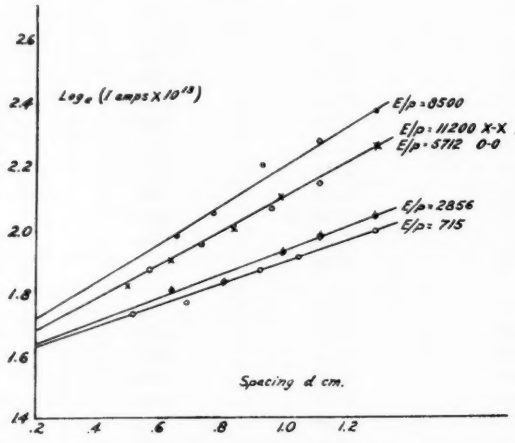

FIG. 8. Typical Curves of Log$_e I$ vs d

cm-mm Hg. However experimenters using the conventional Townsend apparatus and methods have made measurements as high as $E/P = 2000$ volts/cm-mm Hg, and all have found that the logarithm of the current plotted as a function of the spacing gives a straight line, indicating a constant rate of ion generation as long as the spacing does not become too large. Thus whatever changes occur in the mechanism of ion production as we go to high E/P, the transition must be of such a nature that it is not

revealed by the Townsend experiment. In the present investigation data were obtained as high as E/P = 12,000 volts/cm-mm Hg and always the curves of $\log_e I$ plotted against spacing were

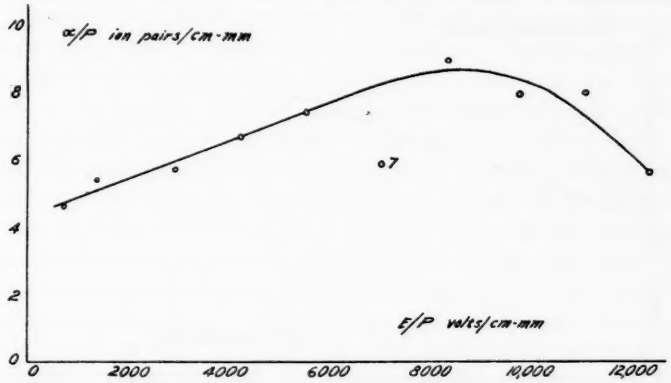

FIG. 9. Experimental Curve of α/P vs E/P

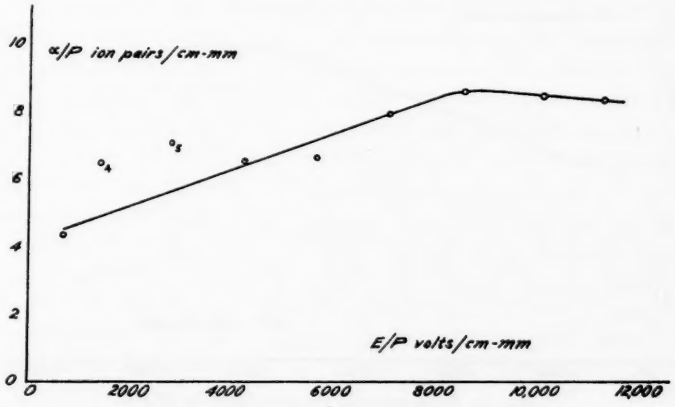

FIG. 10. Experimental Curve of α/P vs E/P

best approximated by straight lines, within the limits of experimental error. The slope of the lines so obtained has been called α for want of a better term even though it is known that a true α cannot exist under these conditions.

The quantity α/P has been plotted as a function of E/P and the resulting curves are illustrated by Figures 9, 10, 11, and 12. While obtaining the data for these curves the pressure was maintained at 0.07 mm Hg and α was measured for values of

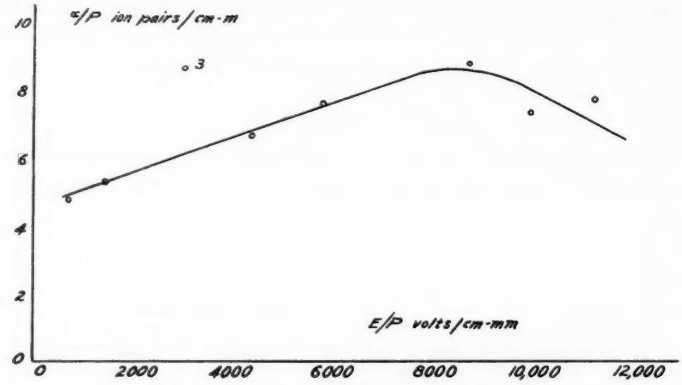

FIG. 11. Experimental Curve of α/P vs E/P

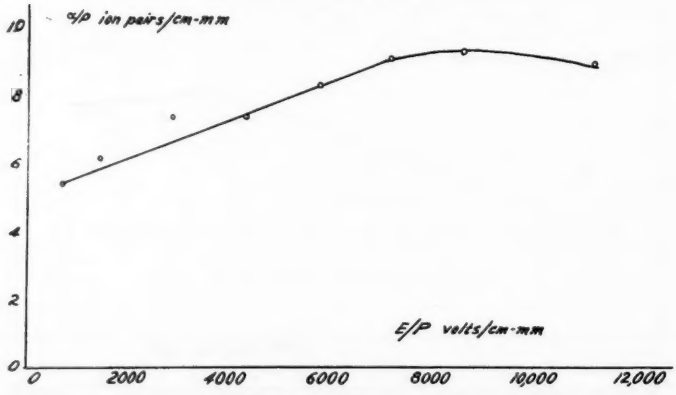

FIG. 12. Experimental Curve of α/P vs E/P

field strength of 50, 100, 200, 300, etc. as high as 800 volts/cm. In one case it was possible to make observations at a field strength of 900 volts/cm but at the extreme values of field, readings were hard to obtain due to the magnified effect of small voltage variations of the power supply and other effects that seemed to be

associated with the collection of electrostatic charges on parts of the equipment. In addition, at the highest fields there was a tendency to establish a self-sustaining discharge and the current became somewhat erratic.

All the α/p vs E/P curves exhibit the same general shape and agree rather well in magnitude at all points. They rise in a more or less linear fashion from $E/P = 700$ volts/cm-mm Hg to $E/P = 8500$ volts/cm-mm Hg and thereafter show a decline. There is good reason to expect peaks in these curves since all ionizing processes become less probable at high energies, but until now they have not appeared in any reliable data. Huxford (10) and Hale (11) have observed peaks in argon and hydrogen gases, respectively, but the maxima they report appear at the low value of $E/P = 700$ volts/cm-mm Hg, which is not in agreement with the results published by other workers. Later on Hale reported that a change in the construction of his tube moved the peak to $E/P = 1300$ volts/cm-mm Hg which would indicate that the result was spurious and of instrumental origin.

The value of α/P indicated by the curves at low values of E/P, where comparison can be made with published data, is in every case somewhat lower than the published values. This may be due to small traces of mercury vapor which were not frozen out by dry ice in the traps. Loeb (12) has pointed out that most gases in the higher range of E/P yield smaller values of α/P when traces of Hg vapor are present. The magnitude of α/P given by the present curves is not unreasonably low and in all probability is reliable. A great amount of care was taken in observation and it was possible to duplicate results as the curves in Figures 9, 10, 11, and 12 indicate. Several points observed were in complete disagreement with the majority of observations and hence may legitimately be disregarded. These points have been labeled 1, 2, and 3 on the graphs.

The most puzzling feature of the results is the appearance of linear $\log_e I$ vs d curves which indicate a uniform rate of ionization. In an attempt to explain these curves an analysis of the conditions existing at very high E/P can be made. It has been shown earlier that when E/P is large, the electron energies must

be large. It follows, therefore, that the likelihood of excitation is very small and we can assume that no energy is lost except by ionization. On the other hand the rate of loss of energy by ionization cannot be nearly as rapid as the rate of gain from the field because, as we have seen on page 149, E/α is always much larger than the ionization potential. The motion of the electrons, therefore, can be regarded without serious error as free fall in a vacuum, with occasional inelastic ionizing collisions. In these collisions their percent loss of energy is negligible and they are not appreciably deflected from the straight path. Under these conditions the rate of ion generation is determined by the likelihood of ionization as shown in Figure 1. The shape of this curve is somewhat complicated, but in order to make an approximate calculation of ion yield it can be represented with sufficient accuracy between 110 and 1000 volts energy by a straight line. Obviously the curve departs completely from the straight line below 100 electron volts but this departure does not affect the ion yield very much, because electrons gain this amount of energy in a distance small compared with the mean free path.

For air the best straight line is represented by

$$L = 0.49 - 0.00033V \tag{11}$$

in which V is the electron energy in electron volts and L is the likelihood of ionization. It is now necessary to modify the derivation given on page 140 to take into account the varying rate of ion generation from point to point. Equation (1) becomes

$$dN = \frac{N}{\lambda} L\, dx \tag{12}$$

where λ is the gas kinetic mean free path of energetic electrons in air. By substituting for L from Equation (11) there results

$$dN = \frac{N}{\lambda} (0.49 - 0.00033V)\, dx$$

Since the rate of energy loss due to ionization is small compared to the rate of gain, the energy of a primary electron when at a distance X from the cathode is EX electron volts, where E is the

electric field strength in volts/cm. If this value is substituted for V and the expression integrated the result is

$$\text{Log}_e N \Big]_0^N = \text{Const.} + \frac{1}{\lambda}\left(0.49x - \frac{Ex^2}{6000}\right)\Big]_0^x$$

In terms of currents between parallel plates d cm apart this becomes

$$\text{Log}_e I = \text{Const.} + \frac{1}{\lambda}\left(0.49d - \frac{Ed^2}{6000}\right) \tag{13}$$

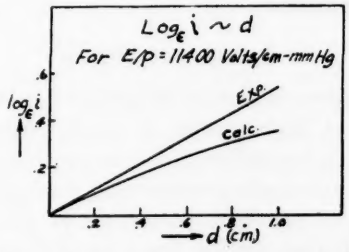

FIG. 13. Comparison of Calculated and Experimental Curve of Log$_e I$ vs d

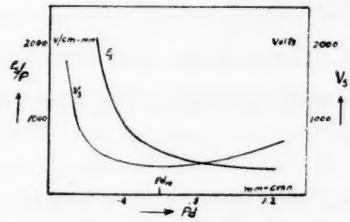

FIG. 14. Sparking Potential and Sparking Gradient as Functions of Pd

Thus, Log$_e I$ is not a linear function of d, and if we compute corresponding values, a curve can be plotted to test the departure from linearity. Figure 13 shows a calculated and an experimental curve for E/P = 11,400 volts/cm-mm Hg. The agreement in magnitude with experiment is only fair but the departure from linearity is not very great and might easily be masked by erratic errors of observation at high values of E/P.

Furthermore, it must be observed that ionization is carried on not only by primary electrons but also by secondary electrons

produced in the space between the plates. These electrons do not fall as far through the field and therefore have lower energies and according to Equation (11) ionize more copiously. Thus for large values of d Equation (13) gives values of I which are somewhat too small, and the curvature is not even as great as appears in Figure 14. Hence it appears that under the given conditions a $\text{Log}_e I$ vs d curve may be obtained which is linear within the experimental error. At present it is impossible to give a quantitative theory as it would seem to require a much more elaborate analysis.

SPARKING POTENTIALS

The general purpose of this investigation has been to study the ionizing process at high values of E/P. Apart from direct measurement of the ionization coefficient α, it is also possible to get some indirect information concerning the ionizing mechanism by measurement of sparking potentials in the same range of E/P. In the following section the general Townsend theory of sparking potentials will be outlined and then the experimental results will be described.

A. Theory of Sparking Potential

Until now the entire discussion has been based upon Equation (1)

$$I = I_0 \epsilon^{\alpha d}$$

In the experimental procedure we have limited spacings to small values and in accordance with Equation (1) the curves of $\text{Log}_e I$ vs d have been found to be straight lines. If, however, the spacing is increased to large values, the curve bends upward, indicating the presence of a new mechanism. A number of explanations for this behavior have been advanced, but it is now generally agreed that the additional current is caused by emission of secondary electrons from the cathode as a result of positive ion bombardment.

Suppose that each positive ion formed causes the emission of K secondary electrons. Denoting the number of secondaries emitted per second by N_s then

$$N_s = K(N - N_0 - N_s) \tag{14}$$

since $(N—N_o—N_s)$ equals the number of positive ions formed per second. Equation (1) now becomes

$$N = \frac{N_0 \epsilon^{\alpha d}}{1 + K - K\epsilon^{\alpha d}} \tag{15}$$

or in terms of currents

$$I = \frac{I_0 \epsilon^{\alpha d}}{1 + K - K\epsilon^{\alpha d}} \tag{16}$$

For small values of d, Equation (16) gives the same linear variation of $\text{Log}_e I$ as Equation (1). As d increases, however, the denominator becomes small, and $\text{Log}_e I$ increases more rapidly. For sufficiently large values of d the denominator becomes zero and the equation indicates an infinite current. Experimentally this simply signifies that any small initial current I_o will increase spontaneously until limited by the onset of some mechanism not provided for in the derivation. It also signifies the appearance of a self sustaining discharge, so that according to the theory the sparking or breakdown potential is calculated by setting the denominator in Equation (16) equal to zero

$$1 + K - K\epsilon^{\alpha d} = 0 \tag{17}$$

In order to obtain an explicit expression for sparking potentials from Equation (17) it is necessary to introduce the customary empirical equation (Engel and Steenbeck) (13)

$$\alpha = PA\epsilon^{-\frac{BP}{E}} \tag{18}$$

Substituting from (18) in (17) it becomes

$$1 + K - K\epsilon^{\left(PA\epsilon^{-\frac{BP}{E_s}}\right)d} = 0$$

where E_s is the sparking gradient. The sparking potential then becomes

$$V_s = \frac{BPd}{\text{Const.} + \log Pd} \tag{19}$$

where constant $= \log_e A - \log_e \log_e \dfrac{1 + K}{K}$

This equation brings out the significant fact that the sparking potential between parallel plates depends upon the product of pressure and spacing.

B. Experimental Data

When the investigation was first undertaken, the intention was to correlate sparking potential and α measurements in the range of high E/P using, if possible, the same discharge tube and the same sample of gas. No mention has been made as yet of the value of E/P at breakdown but if we divide both sides of Equation (19) by Pd we obtain a curve for E_s/P as a function of Pd. A sketch of this curve and of Equation (19) appears in Figure 14, from which it is seen that high E_s/P occurs at values of Pd below Pd_m.

In this range the sparking potential is less for long paths than for shorter ones, so that it is necessary to eliminate all possibility of breakdown over paths longer than the direct path between the plates. Thus there are severe limitations upon the design of a tube suitable for the measurement of both α and sparking potentials. Paths longer than the direct one can, in general, be eliminated in two ways. It is possible to embed the plates in insulating material so that the discharge space becomes a small cylindrical capsule with insulating side walls and metal ends. This design was used in the original measurements by Carr (14) but it is subject to several disadvantages. The plates are not movable for α measurements, and since the chamber must be connected to the vacuum system by a very small tube, the pressure and composition of the gas are highly uncertain. Another serious objection to this design is the fact that static charges can collect on the walls and influence the breakdown potential.

The only alternative way is to design the tube in such a way that while other paths do exist, they are all shorter than the direct path between the plates. This principle has been applied in the design of the tub illustrated in Figure 4. The cathode was made of zinc foil backed by an insulating material so that breakdown could not occur between the cathode supports and the anode. In addition the short crimped foil lead to the cathode

passed through the side tube W in such a way that the distance from it to the anode along any line of the electric field would not be greater than the distance between the parallel plates. The steel head H which formed part of the anode proceeded outward in a conical flare toward the cathode. This was to prevent field

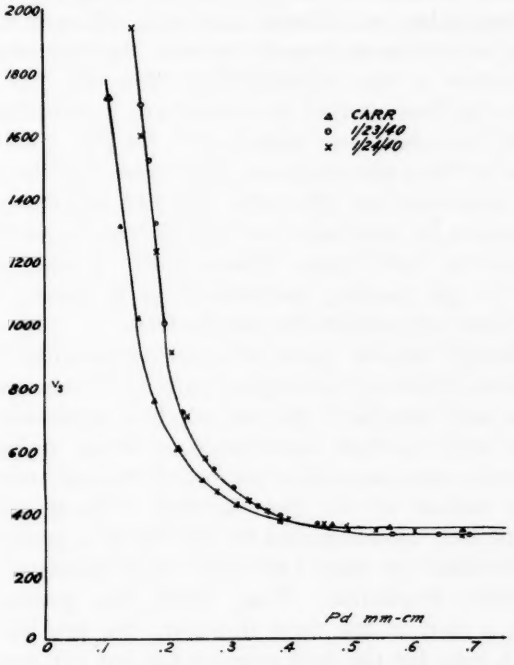

FIG. 15. Comparison of Experimental Sparking Potential Curve and Carr's Data

distortions near the edge of the electrodes that might favor breakdown over paths not in the uniform field.

The electrical circuit for measuring sparking potentials was similar to that of Figure 6 except that the anode was directly grounded, eliminating the electrometer E, Capacitor C, and Potentiometer P from the circuit. To indicate breakdown, a one milliampere meter was placed in series with the cathode circuit and R_3 was made 5×10^5 ohms to limit the current. To

obtain data the spacing was kept constant and the pressure varied to change Pd. At each value of Pd the potential applied to the tube was gradually raised until the milliameter suddenly indicated that a current was passing. This value of potential was taken as the sparking potential for that value of Pd.

The curve obtained in this way is shown in Figure 15 and includes data taken on different days with different samples of gas. The very close agreement between the two sets of data gives assurance of the reproducibility of results. In the same figure there has been plotted for comparison, a curve from Carr's data which indicates lower values of V_s for $Pd < 0.4$ mm-cm. The values of Pd at the minimum point agree, but the minimum sparking potentials are 325 volts and 342 volts respectively. The differences are not large and can perhaps be attributed to wall charges in Carr's tube. There is also a possibility of a difference in gas content, particularly as he used a mercury pump and does not mention the use of a trap.

Even though reliable values of sparking potential have apparently been obtained, the original purpose of measuring α and V_s for the same sample of gas has not been achieved. It was found that with the tube constructed as shown in Figure 4, α measurements were impossible because of leakage currents over the inside surface of the glass between cathode and anode. These could only be eliminated by the use of a graphite guard ring as described on page 149 which made sparking potential measurements impossible. Thus, while the present design represents a step in the right direction, the problem of constructing a tube for the dual purpose has not yet been solved. For this reason no use has been made of the sparking potential data in the analysis, and they have been included only for the sake of completeness. It has been shown, however that this type of tube is entirely satisfactory for the measurement of sparking potentials themselves at values of Pd less than Pd_m.

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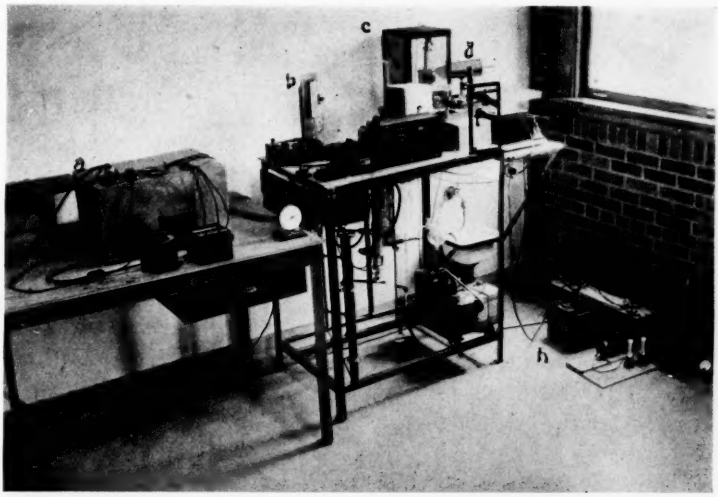
PLATE IV

GENERAL VIEW OF APPARATUS USED IN THE INVESTIGATION

(a) High voltage power supply, (b) McLeod gauge, (c) Electrometer and shield, (d) Variable standard condenser, (e) Ultra violet light source, (f) Discharge tube and shield, (g) Potentiometer, (h) Light source stabilizing circuit.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CANEY CONODONTS OF UPPER MISSISSIPPIAN AGE

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The Caney shales of southeastern Oklahoma, as they are developed in Pontotoc County, attain a thickness of about 500 feet. They seem to represent parts of both the Mississippian and the Pennsylvanian, according to Hyatt.[1] There is difficulty in placing the boundary between the two formations and it is more or less arbitrarily drawn at the contact of a dolomite with a black fissile shale, that occurs about 300 feet above the base of the Caney.

Conodonts are abundant in only a few places where we have collected from the Caney of southeastern Oklahoma and our experiences would indicate that they are patchy in their distribution, both vertically and horizontally. However, this condition may be more apparent than real for there are few places where there is a continuous exposure of great thickness within a limited area, and it is difficult to trace a definite horizon for considerable distances.

The part of the Caney that is definitely assignable to the Mississippian seems to contain conodonts in fair abundance in one or more zones. As a start to building up a zonal distribution of the conodonts, if such distribution exists, we present in the following paragraphs a summary of the conodonts from a single zone and locality that appears to be near the top of the Mississippian division. All of the conodonts here listed and described came from immediately below the higher of two conspicuous bands of large concretions. This zone is exposed at the top of a steep bank of black fissile shale at the side of State Highway 48, about six miles south of Ada, Pontotoc County,

[1] Hyatt, D. L. 1936. Preliminary report on the Fitts Pool, Pontotoc County, Oklahoma: Bull. Am. Assoc. Petr. Geol., vol. 20, p. 958.

Oklahoma. Conodonts are present throughout the upper eight to ten feet but are most abundant in the upper four feet, particularly in a weathered zone a few inches thick just below the concretions. According to Mr. H. L. Griley,[2] who has given us valuable aid in collecting in this region, the zone is near the top of the Mississippian division of the Caney.

AGE OF THE FAUNA

The conodont fauna is too small and is represented by too few perfect specimens to suggest strongly a definite correlation with other formations of the better known Mississippian sections, but there are age limits that the conodonts do set with some degree of accuracy. In the first place there is lacking in the assemblage all representation of the polygnathodellids, the group that appears to be diagnostic of the formations of doubtful age which seem to be younger than Chester and older than the Cherokee, such as the Wapanucka and the Upper Dornick Hills. There is also lacking the polygnathid and pseudopolygnathid groups that continue upward in the Mississippian in diminishing numbers to about the end of the Lower Mississippian or possibly into the Middle Mississippian. The staurognathids, doliognathids, scaliognathids, and bactrognathids,[3] that form an important part of the assemblages in some of the early Middle Mississippian zones are entirely lacking in this division of the Caney.

The inference, then, is that the fauna described in this paper belongs in the Upper Mississippian (Chester Group). Not only does the negative evidence point to this assignment but the fauna that is present has a distinct Chester aspect.

Although the Pitkin has but few species in common with the lower Caney there are no other Upper Mississippian conodont faunas of which we have knowledge that are more closely related than those from the Pitkin of northeastern Oklahoma and north-

[2] Personal communication.

[3] The genera *Staurognathus*, *Doliognathus*, *Scaliognathus*, and *Bactrognathus* are described by Branson and Mehl in "New and little known Carboniferous Conodont Genera" in press at the time of this writing, Jour. Paleontology (probable date of publication January or February, 1941).

western Arkansas and the lower Caney of Oklahoma. We anticipate that additional conodont collections from the Mississippian Caney and the Upper Mississippian of other regions will establish this suggested correlation.

DETAILS OF THE FAUNA

The Caney fauna is not abundant in genera and species, but some of the figured and unidentified specimens indicate that many more species should appear in later collecting. Although but two species of *Gnathodus* are listed, one of which is perhaps the most characteristic form of the fauna, the genus is represented by a few other species the remains of which are too fragmentary to justify specific description. The same is true for the genus *Cavusgnathus*, representative fragments of which indicate the presence of one or more species in addition to the single form figured.

One of the surprising features of the fauna is the small number of hindeodellids. Our methods of segregation give some assurance that all fragments of conodonts are recovered from the particular spot that is sampled. The small number of hindeodellid scraps should preclude their anatomical association with the cavusgnathids which are much more abundant. The association of these two forms with *Prioniodus* in the Heath formation of Montana seems to be one of the evidences that induced Scott[4] to believe that teeth of three so called genera were assembled in the same mouth.

Genus HINDEODELLA Ulrich and Bassler

Hindeodella undata Branson and Mehl, n. sp.

Plate V, figure 3

Blade-like with aboral edge slightly sinuous laterally and oral edge markedly sinuous with the extent of each lateral swing accentuated by a denticle of the major series. Denticles circular in cross section or laterally compressed, the difference in size

[4] Scott, H. W. 1934. The Zoological Relationships of the Conodonts: Jour. Pal., vol. 8, pp. 448-455.

between the major and minor series evident but less conspicuous than common among hindeodellids, from three to six of the smaller size intervening between each pair of the major series, with three or four being the common number. Aboral edge rounded, traversed by a faint groove. The attachment scar evident in direct later view from either side. Termini unknown.

Syntypes.—Univ. Missouri, C543–4.

Occurrence.—Lower division of the Caney, Pontotoc County, Oklahoma.

OTHER HINDEODELLIDS

Plate V, figures 1, 2, 9

Specimens of both bar- and blade-like hindeodellids, represented only by mid-length sections in our collections, indicate a moderate representation of these two general types, but without termini there are no evident characters that justify specific reference. In addition to these there is present in the fauna a form represented by a distinctive anterior terminus (figure 9), also too poorly preserved to justify specific description.

Figured specimens.—Univ. Missouri, C543–3, C545–2, C544–3.

Occurrence.—Lower division of the Caney, Pontotoc County, Oklahoma.

Genus LIGONODINA Ulrich and Bassler

Ligonodina tenuis Branson and Mehl, n. sp.

Plate V, figures 13, 14

Posterior bar short, straight or slightly arched, denticles exceptionally small, sub-terminal fang long and slender, gently tapering, straight or slightly curved inward, inclined posteriorly through a sharp bend at the base, somewhat compressed laterally with rounded anterior and posterior edges. Antero-lateral process short, directed inward and slightly back and down with the chief denticulation on the base of the fang rather than on the process. A pit of moderate size beneath the fang extends back on the aboral edge of the bar as a faint groove. Attachment scars are evident at the anterior end of the bar in direct lateral view, that of the inner side larger than the others.

Holotype.—Univ. Missouri, C545–3.

Occurrence.—Lower division of the Caney, Pontotoc County, Oklahoma.

OTHER LIGONODINIDS

Plate V, figure 11

Numerous broken pieces, both straight and curved, of a size and denticulation such that they may represent the posterior bar of ligonodinids, are present in our lower Caney collections and indicate several distinctive forms too fragmentary for specific reference.

Figured specimen.—Univ. Missouri, C544–1.

Occurrence.—Lower division of the Caney, Pontotoc County, Oklahoma.

Genus EUPRIONIODINA Ulrich and Bassler

Plate V, figures 17, 18

A comparatively small number of specimens in our collections from the lower division of the Caney indicates the presence of several species referable, with some degree of certainty, to the genus *Euprioniodina*. None of these specimens is sufficiently complete to justify specific description.

Figured specimens.—Univ. Missouri, C546–1 and C545–1.

Occurrence.—Lower division of the Caney, Pontotoc County, Oklahoma.

Genus LONCHODINA Ulrich and Bassler

Plate V, figures 10, 12

In our collections from the lower Caney there are numerous more or less doubly curved bars with long discrete denticles, none sufficiently complete for positive identification, that probably represent two or more species of *Lonchodina*. The small number of such fragmentary specimens indicates that this genus is of minor importance in the fauna.

Figured specimens.—Univ. Missouri, C544–3 and C544–2.

Occurrence.—Lower division of the Caney, Pontotoc County, Oklahoma.

Genus METALONCHODINA Branson and Mehl[5]

Plate V, figure 15

In addition to fragmentary specimens of typical metaloncho-dinids there are broken specimens of a distinctive type in our collections from the lower division of the Caney that probably should be referred to this group. The most distinctive feature in these doubtful specimens is the abnormally large pit with flaring margins beneath the apical denticle.

Figured specimen.—Univ. Missouri, C543–5.

Occurrence.—Lower division of the Caney, Pontotoc County, Oklahoma.

Genus SPATHOGNATHODUS Branson and Mehl

Spathognathodus commutatus Branson and Mehl[6]

Plate V, figures 19–22

It is possible that the specimens from the lower division of the Caney, indentified as *S. commutatus* are specifically distinct. In most of them the posterior end of the aboral cup is much less pointed than in the specimens from the Pitkin limestone. However, there are specimens from each of these formations that represent intermediate development and we prefer to recognize the species as sufficiently variable to include the extremes.

Figured specimens.—Univ. Missouri, C542–2 (fig. 19), C541–5.

Occurrence.—Lower division of the Caney, Pontotoc County, Oklahoma.

Genus GNATHODUS Pander

Gnathodus pustulosus Branson and Mehl, n. sp.

Plate V, figures 32–39

Axis straight or slightly curved, blade as long or longer than

[5] This genus is described by Branson and Mehl in the article listed on page 168.

[6] This genus and the species *S. commutatus* is described by Branson and Mehl in the article listed on page 168.

cup, of uniform width except for a slight increase near the anterior end, denticles in adult specimens about fifteen, sub-equal except for a few of larger size at the anterior end, with short free apices. Carina comparatively high, sharp, consisting of a nodose ridge, down curved at the posterior end in lateral view, and extending appreciably beyond the cup proper. Cup large, wider than long, the outer much wider than the inner part, greatest diameter near the anterior side and diagonal to the axis; oral surface of inner part more or less parapet-like with closely spaced transverse ridges inclined toward the carina, outer part marked by fine and coarse rounded nodes with more or less concentric alignment that parallels the outer margin.

Holotype.—Univ. Missouri, C542–1.

Occurrence.—Lower division of the Caney, Pontotoc County, Oklahoma.

GNATHODUS TEXANUS Roundy

Plate V, figures 23–25

Gnathodus texanus Roundy, 1926: U. S. Geol. Survey, Prof. Paper 146, p. 12, figs. 7a–8b.

Many specimens from the lower division of the Caney cannot be distinguished from *Gnathodus texanus* described by Roundy from the Barnett shales of Texas.

Figured specimens.—Univ. Missouri, C546–2 (fig. 23), C542–3.

Occurrence.—Lower division of the Caney, Pontotoc County, Oklahoma.

Genus PRIONIODUS Pander

Prioniodus scitulus Branson and Mehl, n. sp.

Plate V, figures 5, 6

Posterior bar straight or very slightly arched, laterally straight or slightly concave inward, short, thin; aboral edge truncated and medially grooved. Bar denticles slightly inclined backward, laterally compressed, small, slender, sub-equal, with gradually tapering sharp free apices. Terminal fang erect, straight or somewhat curved, concave inward, laterally compressed with

sharp edges, exceptionally long and slender, gradually tapering to a sharp point; produced aborally in a sharply pointed process that extends considerably below the aboral edge of the bar; anterior edge, viewed laterally, presenting a regular, gently convex outline. Excavation beneath the fang shallow, narrow, with sharp lateral edges neither of which is greatly flared.

Syntypes.—Univ. Missouri, C545–4.

Occurrence.—Lower division of the Caney, Pontotoc County, Oklahoma.

Remarks.—There is another prioniodid in the lower Caney fauna, too poorly represented for description, that resembles *P. scitulus* closely in gross features, differing in the presence of a minute pit beneath the fang rather than an excavation, and in the presence of an attachment scar on the lateral faces of the fang at its postero-lateral margins.

Prioniodus varians Branson and Mehl, n. sp.

Plate V, figures 7, 8

Posterior bar of moderate length, slightly arched, laterally curved, concave inward, thin; aboral edge truncated and medially grooved; denticles small, erect, subequal, slightly compressed laterally, closely crowded with short pointed free apices. Terminal fang long, tapering regularly, comparatively slender; anterior edge straight in lateral view, outer face from transversely flat at base to convex at mid-height, inner face sharply convex transversely; edges sharp, inner face convex from base to tip, the outer edge of the upper part of the fang twisting inward; aboral projection sharp, of moderate length, postero-aboral edge shallowly excavated with sharp lip, the inner of which flares outward.

Holotype.—Univ. Missouri, C546–3.

Occurrence.—Lower division of the Caney, Pontotoc County, Oklahoma.

Remarks.—There is some doubt as to what constitutes specific characters among the prioniodids. The type of *P. varians* shows no indication of the suppression of denticles by the lateral spread of those that become discrete oral points in mature

specimens. Associated with and possibly representing variants of this species are specimens that in gross features resemble the type closely. They differ in that with transmitted light minute germ denticles are evident that are suppressed by the exceptional growth of others. In some such specimens there is a regular alternation of from two to four minute suppressed denticles between each pair of oral terminations.

P. varians resembles closely *P. recurvus* Branson and Mehl, from the Bushberg, differing chiefly in the truncated rather than sharp beveled aboral edge of the bar and the more sharply pointed aboral projection of the fang in the latter.

Genus HIBBARDELLA Ulrich and Bassler

The generic description of *Hibbardella* by Ulrich and Bassler was based on the natural assumption that it is a simple bilaterally symmetrical arch with discrete limb denticles and an exceptionally large denticle at the apex. The type of the genus, *Hibbardella angulata* (Hinde) Ulrich and Bassler, and many of the specimens that have been referred to the genus subsequently, have been found on a bedding plane of hard fissile black shale. It follows, therefore, that the specimens are nearly flat, either from their nature or because of crushing, and that one side only of the arch is exposed. Curvature of the denticles other than that in the plane of the arch is not evident and any projections normal to the plane of the arch have been broken off by splitting the shale or are concealed beneath the specimen. Careful examination of matrix imbedded specimens that are referable to *Hibbardella* show a fractured surface below the apical denticle on the face of the arch or, in the absence of this, such a fracture on the opposite side when the specimen is removed. Likewise, all matrix free specimens that would otherwise be identified as *Hibbardella* show either a bar projecting normal to the plane of the arch on one side, or the fracture resulting from the loss of such a bar. Although this was not observed by Branson when he studied the type material of the genus it is reasonably certain that the fracture is observable or that the process is present on the other side of the specimen.

Before we noted the departure of typical hibbardellids from the generic analysis given by Ulrich and Bassler we had established the genus *Trichognathus* for *Hibbardella*-like forms with a posterior bar (assuming a transverse position for the arch) and a deep excavation beneath the apex of the arch at the union of the arch limbs and the posterior bar. We have referred to *Trichognathus* a number of species that now appear to be typical hibbardellids, and have been followed in this by other writers.

A careful examination of the type of *Trichognathus* and specimens of similar construction, from formations ranging in age from Ordovician to Pennsylvanian, indicates that *Trichognathus*, rather than being preoccupied by *Hibbardella*, is a distinct genus. It seems needful to revise the description of *Hibbardella* and, in an appropriate place, reassign to this genus some of the species that have been referred to *Trichognathus*.

Revised description of *Hibbardella*:

Highly arched bar-like teeth, bilaterally symmetrical, with limbs of equal length that bear discrete erect or recurved denticles, an erect or recurved denticle of large size at the apex of the arch; a bar bearing discrete denticles extending back from the base of the apical denticle normal to the plane of the arch; without conspicuous excavation beneath the apex of the arch at the union of the arch limbs and the posterior bar.

Remarks.—This genus resembles closely *Trichognathus*, differing chiefly in that the latter is deeply excavated beneath the apex of the arch at the union of the arch limbs and the posterior bar. In its later development *Hibbardella* may have the posterior bar very much shortened and in some species there is only a vestige of the arch limbs.

HIBBARDELLA (?) sp. indet.

Plate V, figure 4

Hibbardella is but sparingly represented in this fauna and such specimens in our collections as can be referred to the genus with certainty are too fragmental to allow specific identification. Among the remains that are probably to be referred to the genus

are numerous fragments of straight bars with discrete inclined denticles. Many such fragments have been inadvertently referred to the group designated as *Lonchodus*, a generic designation without definition. Such fragments as herewith figured are referred with question to *Hibbardella* rather than to *Ligonodina* because most of the recognizable forms in this fauna referable to the latter give evidence of a posterior bar that is strongly downcurved.

Figured specimen.—Univ. Missouri, C544–5.

Occurrence.—Lower division of the Caney, Pontotoc County, Oklahoma.

Genus OZARKODINA Branson and Mehl

Ozarkodina mutabilis Branson and Mehl, n. sp.

Plate V, figure 16

Blade deep, arched with sharpest flexure back of the apex, laterally straight except for an inward flexure of the anterior end and an outer flexure of the posterior end, greatest thickness near the base of the free denticles with gradual diminution to a thin aboral edge. Denticles of anterior limb of irregular large size, about five, each the result of coalescence of two to four germ denticles. Apical denticle long and exceptionally wide at its base, inclined backward. Denticles of posterior limb somewhat irregular, smaller than anterior denticles, ranging in number from about nine to fourteen, germ denticles more numerous some being suppressed by the growth of others rather than combined; apical pit small, sharply pointed, directed forward, antero-posteriorly elongate, without lateral flare.

Syntypes.—Univ. Missouri, C542–5.

Occurrence.—Lower division of the Caney, Pontotoc County, Oklahoma.

Genus CAVUSGNATHUS Harris and Hollingsworth

Cavusgnathus cristata Branson and Mehl, n. sp.

Plate V, figures 26–31

Large forms with high platform and deep narrow trough. Outline in oral view long and narrow with sharply pointed

Before we noted the departure of typical hibbardellids from the generic analysis given by Ulrich and Bassler we had established the genus *Trichognathus* for *Hibbardella*-like forms with a posterior bar (assuming a transverse position for the arch) and a deep excavation beneath the apex of the arch at the union of the arch limbs and the posterior bar. We have referred to *Trichognathus* a number of species that now appear to be typical hibbardellids, and have been followed in this by other writers.

A careful examination of the type of *Trichognathus* and specimens of similar construction, from formations ranging in age from Ordovician to Pennsylvanian, indicates that *Trichognathus*, rather than being preoccupied by *Hibbardella*, is a distinct genus. It seems needful to revise the description of *Hibbardella* and, in an appropriate place, reassign to this genus some of the species that have been referred to *Trichognathus*.

Revised description of *Hibbardella*:

Highly arched bar-like teeth, bilaterally symmetrical, with limbs of equal length that bear discrete erect or recurved denticles, an erect or recurved denticle of large size at the apex of the arch; a bar bearing discrete denticles extending back from the base of the apical denticle normal to the plane of the arch; without conspicuous excavation beneath the apex of the arch at the union of the arch limbs and the posterior bar.

Remarks.—This genus resembles closely *Trichognathus*, differing chiefly in that the latter is deeply excavated beneath the apex of the arch at the union of the arch limbs and the posterior bar. In its later development *Hibbardella* may have the posterior bar very much shortened and in some species there is only a vestige of the arch limbs.

HIBBARDELLA (?) sp. indet.

Plate V, figure 4

Hibbardella is but sparingly represented in this fauna and such specimens in our collections as can be referred to the genus with certainty are too fragmental to allow specific identification. Among the remains that are probably to be referred to the genus

are numerous fragments of straight bars with discrete inclined denticles. Many such fragments have been inadvertently referred to the group designated as *Lonchodus*, a generic designation without definition. Such fragments as herewith figured are referred with question to *Hibbardella* rather than to *Ligonodina* because most of the recognizable forms in this fauna referable to the latter give evidence of a posterior bar that is strongly downcurved.

Figured specimen.—Univ. Missouri, C544–5.

Occurrence.—Lower division of the Caney, Pontotoc County, Oklahoma.

Genus OZARKODINA Branson and Mehl

Ozarkodina mutabilis Branson and Mehl, n. sp.

Plate V, figure 16

Blade deep, arched with sharpest flexure back of the apex, laterally straight except for an inward flexure of the anterior end and an outer flexure of the posterior end, greatest thickness near the base of the free denticles with gradual diminution to a thin aboral edge. Denticles of anterior limb of irregular large size, about five, each the result of coalescence of two to four germ denticles. Apical denticle long and exceptionally wide at its base, inclined backward. Denticles of posterior limb somewhat irregular, smaller than anterior denticles, ranging in number from about nine to fourteen, germ denticles more numerous some being suppressed by the growth of others rather than combined; apical pit small, sharply pointed, directed forward, antero-posteriorly elongate, without lateral flare.

Syntypes.—Univ. Missouri, C542–5.

Occurrence.—Lower division of the Caney, Pontotoc County, Oklahoma.

Genus CAVUSGNATHUS Harris and Hollingsworth

Cavusgnathus cristata Branson and Mehl, n. sp.

Plate V, figures 26–31

Large forms with high platform and deep narrow trough. Outline in oral view long and narrow with sharply pointed

posterior end, greatest width at or slightly back of mid-length. Outer side nearly straight throughout all but the posterior part; inner side straight in the anterior third or half and regularly convex back of this. Oral outline of inner side straight in lateral view, outline of outer side straight or slightly arched except for the crest of the blade; inner margin ending only a short distance back of the anterior end of the blade. Aboral outline in lateral view nearly straight and nearly parallel with the oral margin. Oral trough slightly sinuous or straight, sharp and smooth bottomed except at the posterior end where a faint median carina appears which is either complete or consists of low isolated nodes; inner face of bounding parapets marked by more or less aligned nodes or complete sharp ridges, transverse to the face, irregularly developed and disposed. Outer parapet produced into a short free blade the oral edge of which extends posteriorly on the edge of the plate proper as far or farther than the length of the free blade, and is offset sharply at its posterior end above the parapet edge. Oral edge of blade sharply crenulate through the development of five to seven large and small laterally compressed sharp-edged denticles. Aboral side of tooth sharp-edged in its anterior and posterior fourths, mid-length expanded into an elongate sharp-edged moderately deep cup with the deepest part at the level of the posterior end of the blade; cup from bilaterally subsymmetrical to symmetrical with greatest width most commonly near the anterior end.

Holotype.—Univ. Missouri, C542–4.

Occurrence.—Lower division of the Caney, Pontotoc County, Oklahoma.

PLATE

EXPLANATION OF PLATE V

All figures × 25 unless otherwise stated

Figs. 1, 2. Hindeodellids. Univ. Missouri, C543 3, x11, C545-2.

Fig. 3. *Hindeodella undata*, n. sp. Lateral view of one of two syntypes, Univ. Missouri, C543 4.

Fig. 4. *Hibbardella*, sp. indet. Part of posterior bar, Univ. Missouri, C544-5.

Figs. 5, 6. *Prioniodus scitulus*, n. sp. Inner lateral views of two syntypes, Univ. Missouri, C545 4, x11.

Figs. 7, 8. *Prioniodus varians*, n. sp. Inner and outer lateral views of two specimens, Univ. Missouri, C546-3 (fig. 8, holotype), C546-5 (a variant).

Fig. 9. *Hindeodella* sp. Outer lateral view of the anterior end of a distinctive form, Univ. Missouri, C544-3.

Fig. 10. *Lonchodina* sp. Univ. Missouri, C544-4.

Fig. 11. *Ligonodina?* sp. Nearly complete posterior bar of a distinctive form, Univ. Missouri, C544-1.

Fig. 12. *Lonchodina?* sp. Univ. Missouri, C544-2.

Figs. 13, 14. *Ligonodina tenuis*, n. sp. Outer and inner lateral views of Univ. Missouri, C545-3 (holotype), C550-3, both x11.

Fig. 15. *Metalonchodina?* sp. Univ. Missouri, C543-5.

Fig. 16. *Ozarkodina mutabilis*, n. sp. Lateral view of one of two syntypes, Univ. Missouri, C542-5.

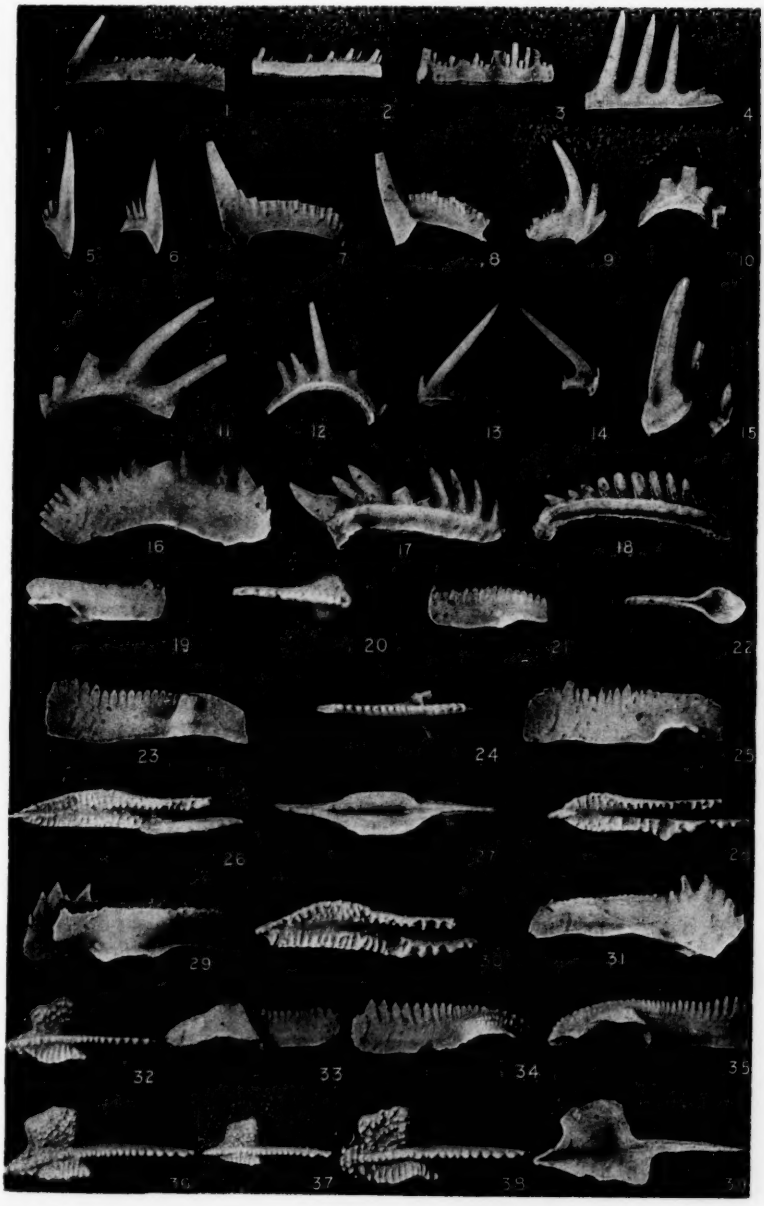
Figs. 17, 18. *Euprioniodina?* sp. Lateral views of two incomplete specimens, Univ. Missouri, C546-1, C545-1.

Figs. 19, 22. *Spathognathodus commutatus* Branson and Mehl. Inner lateral, oral, outer lateral, and aboral views of four specimens, Univ. Missouri, C542-2 (fig. 19), C541-5.

Figs. 23-25. *Gnathodus texanus* Roundy. Inner lateral, oral, and outer lateral views of three specimens, Univ. Missouri, C542 3 (fig. 23), C546-2.

Figs. 26-31. *Cavusgnathus cristata*, n. sp. Oral, aboral, oral, inner lateral, oral, outer lateral views of six specimens, Univ. Missouri, C542-4 (holotype, fig. 29), C543-2.

Figs. 32, 39. *Gnathodus pustulosus*, n. sp. Oral, inner lateral, outer lateral, outer lateral, oral, oral, oral, and aboral views of eight specimens, Univ. Missouri, C542-1 (holotype, fig. 36), C543-1.



BRANSON AND MEHL CANEY MISSISSIPPIAN CONODONTS

CONODONTS FROM THE KEOKUK FORMATION

E. B. BRANSON AND M. G. MEHL

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Little has been published concerning the conodonts representing the interval between the Lower Mississippian and the Pennsylvanian. Regularly, over a period of years, we have included an investigation of this interval in an attempt to build up a picture of conodont history, but the results have been disappointing. We attribute the meagre results of our efforts to the fact that they have been confined largely to sediments of this age in the Mississippi Valley within which limestone, rather than shale, representatives of the various formations involved are typical.

A large number of Paleozoic limestones have yielded small assemblages of conodonts upon digestion with acetic and similar acids. These do not compare with the abundance and variety in the assemblages from productive shales and it is likely that the limestone segregations do not truly reflect the conodont development of the time. There is no assurance, for instance, that some of the small delicate specimens were not carried into the lime zone in suspension from elsewhere. The residue from some of the productive limestone samples is found to contain quartz grains of considerable size. There is also the possibility that there were limited, clear water conodont developments as opposed to the normal abundant development in water containing some sediments.

Regardless of the lack of information concerning the sedimentary associations of the conodonts it is safe to assume that, in general, limestones do not provide as large faunas as those sections with interbedded shales.

It follows that any conodont faunas from the Middle or Upper Mississippian, largely represented by limestones, are of importance out of proportion to their size and variety. We feel justified

in describing the conodonts from the Keokuk, regardless of the fact that they almost certainly do not give an adequate picture of conodont development of that time.

NATURE OF THE KEOKUK FAUNA

The most characteristic and abundant form in this fauna is a single species of *Streptognathus*-like conodont which we have designated as the type of a new genus. Specimens of this species are several times more abundant than those of any other form. A very distinctive species of Gnathodus stands next in abundance. The hindeodellids are almost lacking in the most productive samples that we have examined. We have found none of distinctive form or sufficiently well represented to permit specific identification with certainty. The genus *Prioniodus* occurs in large numbers but not in great variety. *Hibbardella* is represented in some abundance by a highly modified form, and typical *Ligonodinas* of one or more species are present. *Ozarkodina* and *Spathodus* are sparingly represented, but neither by distinctive forms.

COLLECTING LOCALITIES

The conodonts in our Keokuk collections that were obtained at and near the type locality in Iowa are too few to permit a satisfactory comparison with the much more abundant collections from several places in Missouri. However, it is evident that there is little age difference in the specimens from the Iowa and the Missouri localities. In Missouri three widely separated localities, as listed below, have provided the bulk of our Keokuk conodonts.

The Troy locality.—About 2 miles east of Troy, on the Cuivre River in Lincoln County, State Highway No. 47 a section of Keokuk shales and limestones is exposed in a cut, some zones of which have been moderately productive of conodonts. This section was elsewhere inadvertently designated as Burlington, Hannibal, and Grassy Creek[1] before its conodont fauna was

[1] Branson, E. B. 1938. Stratigraphy and Paleontology of the Lower Mississippian of Missouri, Part II, Univ. Missouri Studies, vol. 13, p. 46, fig. 11.

analyzed. The most productive zones in this section include one immediately above the unit labeled "Hannibal" in the reference cited, and one at the top of the zone labeled "Grassy Creek."

The Calwood locality.—In a small abandoned quarry in Burlington limestone about one-half mile east of Calwood, Callaway County, Missouri, appear irregular stringers of green and buff clay, the relationships of which indicate that they constitute stratigraphic leaks. From some of these stringers well preserved conodonts of Keokuk age have been segregated. In this region erosion removed the Keokuk before the first Pennsylvanian sea invasion, and the Burlington is now immediately overlain by the Cherokee (basal Pennsylvanian). For this reason there is no direct evidence of the Keokuk age of some of the clay stringers in the Burlington except the conodonts themselves. Accordingly, none of the specimens from this locality has been used as type material although the specimens are almost identical with materials from other well authenticated Keokuk localities.

The Sylvan Beach locality.—Along U. S. Highway No. 66 in the vicinity of Sylvan Beach, St. Louis County, Missouri, occurs an almost continuous section from the basal Mississippian into the St. Louis formation. Our Keokuk conodont collections from this locality have come from several horizons but the most abundantly productive zone is at the top of a shale series in what we assume to be the upper part of the Keokuk. All of the types designated in the following paragraphs came from this zone.

DESCRIPTION OF GENERA AND SPECIES

Genus TAPHROGNATHUS Branson and Mehl, n. gen.

Ety. *taphre*, a trench; *gnathus*, jaw.

Elongate platform teeth with medially trenched oral surface, median blade, and completely excavated aboral side. Lateral margins or parapets of oral side nodose, transversely ridged, or smooth. Blade continued into the median trench as a short

carina with major length of trench smooth or faintly carinate. Aboral cup bilaterally subsymmetrical to noticeably asymmetrical, with laterally flaring lips.

Genotype.—*Taphrognathus varians,* n. sp.

Remarks.—Taphrognathus has much in common with *Streptognathodus* and little can be offered in the way of generic analysis to separate the two groups satisfactorily. We interpret these two groups as parallel developments, originating at two entirely different times, probably from the same stock. Whether they overlap in time has not been determined. The first of the typical streptognathodids appears in the early Pennsylvanian and is closely related to the idiognathodids. On the other hand, the typical taphrognathids appear in or about Keokuk time and, we believe, give rise to the cavusgnathids. No taphrognathids have been found in the Upper Mississippian although a fairly abundant conodont fauna of this epoch is known.

Taphrognathus varians Branson and Mehl, n. sp.

Plate VI, figures 27–33, 35–40

Long and narrow with axis more or less curved laterally, concave inward. Outline of platform in oral view lanceolate, greatest width near mid-length, with a tendency toward lateral constriction, chiefly of the inner side, between mid-length and the anterior end; posterior end extended, acuminate. Median trench narrow and deep, smooth bottomed except for the anterior end which is occupied for a short distance by an abruptly ending carina, and the posterior end that is nodose to carinate; internal faces of lateral bounding parapets irregularly transverse ridges. Blade long, with sharply crenulate oral edge highest at or slightly in front of mid-length. Aboral cup with flaring lateral margins much longer than wide, extending as a groove along the blade and the elongated posterior end of the plate, anterior and posterior ends sharp; greatest depth in front of mid-length.

Holotype.—Univ. Missouri, C578–5.

Occurrence.—Keokuk, Sylvan Beach, St. Louis County, Missouri.

Remarks.—To this species we have assigned specimens of considerable variety ranging from those with smooth bounding parapets on the oral surface to those with well developed sharp transverse ridges. Likewise we see no basis for excluding specimens that agree otherwise with the gross development but are transversely ridged at the posterior end rather than distinctly carinate. One specimen that is doubtfully referred to this species, although showing an offset at the posterior end of the anterior carina, has the blade and carina almost aligned with the outer lateral parapet. Obviously this specimen might be assigned to the genus *Cavusgnathus.*

Genus GNATHODUS Pander

Gnathodus linguiformis Branson and Mehl, n. sp.

Plate VI, figures 18–26

Axis somewhat curved laterally most strongly in its posterior half. Blade comparatively thick, with blunt, closely crowded, slightly compressed denticles; extending across and behind the cup is a gradually widening carina which in its posterior half is crossed by transverse, slightly curved ridges that are concave forward. Oral edge of carina down-curved at its posterior end to meet the aboral outline. Inner part of oral surface of cup produced into a crescentic lobe, concave in the middle, consisting of two or more partially or completely fused nodes. Outer side marked by one prominent node, or several in transverse, more or less ridge-like alignment, slightly back of the crescent of the opposite side. Aboral cup as wide as long, excepting at its pointed anterior and somewhat longer posterior ends, with greatest transverse diameter diagonal to the axis; the smaller, antero-axial angle on the inner side.

Holotype.—Univ. Missouri, C546–4.

Occurrence.—Keokuk, Sylvan Beach, St. Louis County, Missouri.

Remarks.—There is a variety among specimens referred to this species that is not to be accounted for as different stages of growth alone. In specimens that are clearly mature there is a

variation between one and several nodes in the laterally directed ridge of the outer part of the cup and some specimens, possibly mature, lack all markings on the outer part of the cup. There seems to be a regular progression toward increased breadth and tongue-like development of the posterior end of the carina from young to old specimens. It is this tongue-like development that sets *G. linguiformis* off from *G. texanus*, var. *bicuspidus* Roundy. However, it is possible that Roundy's type is a young individual of the form here described.

Genus OZARKODINA Branson and Mehl

Indeterminate Ozarkodinids

Plate VI, figures 2, 3

A small number of fragmentary specimens of *Ozarkodina* indicate the presence of at least two species of this genus in the Keokuk. One of these is a thin comparatively wide blade. Another is narrow and thick, and slightly curved laterally. Both have only slightly compressed denticles. Neither group is sufficiently well represented to justify specific reference.

Figured specimens.—Univ. Missouri, C577–3, C575–1.

Genus HIBBARDELLA Ulrich and Bassler

Hibbardella abnormis Branson and Mehl, n. sp.

Plate VI, figure 14

Limbs of arch much reduced, consisting of little more than denticulation on the antero-laterally extended base of the apical denticle. Apical denticle greatly expanded, recurved, gently tapered, laterally compressed, with rounded faces in its proximal half and pointed anterior and posterior carina in its distal half. Posterior bar short or lacking, with a small number of minute widely spaced denticles or none. Aboral side of basal expansion of apical denticle almost a plane, unexcavated except for a median groove, antero-lateral margins rolled parapet-like to form the major portions of the aborted arch limbs.

Holotype.—Univ. Missouri, C577–1.

Occurrence.—Keokuk, Sylvan Beach, St. Louis County, Missouri.

Remarks.—This form varies considerably from youth to old age, primarily in the regular increase in the width and length of the base. In some mature specimens there is no posterior bar and the denticulation present in most young specimens may become obscured with age.

Genus TRICHOGNATHUS Branson and Mehl

Trichognathus sp. indet.

Plate VI, figure 13

In our Keokuk conodont collections the genus *Trichognathus* is represented by at least one species of typical trichognathid development. Although it is too poorly preserved to permit specific reference some of the characteristics are evident. The posterior bar is very short and studded with a few very small widely spaced denticles. The arch is very narrow with short straight wing-like limbs that take part in an exceptionally deep thin walled excavation beneath a large, slightly recurved, apical denticle, the faces of which are undifferentiated.

Figured specimen.—Univ. Missouri, C578–4.

Genus LIGONODINA Ulrich and Bassler

Ligonodina levis Branson and Mehl, n. sp.

Plate VI, figure 10

Terminal fang broadly recurved, somewhat laterally compressed, with rounded anterior and posterior sides. Posterior bar delicate, short, edentulous or marked by a small number of minute denticles. Antero-inferior process directed abruptly in and back with its comparatively large denticles pointing inward. Aboral surface beneath the fang laterally expanded, shallowly excavated, bilaterally symmetrical.

Holotype.—Univ. Missouri, C574–1.

Occurrence.—Keokuk, Sylvan Beach, St. Louis County, Missouri.

Genus PRIONIODUS Pander

Prioniodus cassilaris Branson and Mehl, n. sp.

Plate VI, figures 11, 12, 15, 17

Fang laterally compressed with sharp anterior and posterior edges, gently tapering from an antero-posteriorly wide base; in lateral view straight or slightly recurved with slightly concave anterior outline, in some cases convex in its proximal half; moderately extended aborally. Posterior bar arched, slightly curved laterally, of moderate length, comparatively thick and narrow; denticles not confluent at their bases, but offset with the sides of the bar, moderately compressed, closely crowded but distinct, with short free pointed apices. Aboral excavation beneath the fang without laterally flaring lips, very shallow, bilaterally almost symmetrical, greatly extended antero-posteriorly and extending as a groove on the flat aboral surface of the posterior bar.

Holotype.—Univ. Missouri, C575–3.

Occurrence.—Keokuk, Sylvan Beach, St. Louis County, Missouri.

Remarks.—In its typical development this species is readily distinguished by the absence of a flared lip on either side of the aboral cup, and the lateral offset of the posterior bar at the base of the denticles. The anterior outline of the fang is variable, but generally slightly concave. Typical specimens show no attachment scar in lateral view at the base of the fang but in some specimens, otherwise typical, such a scar is evident.

Prioniodus sp. indet.

Plate VI, figures 8, 9

Our Keokuk conodont collections contain a small number of broken specimens of a distinctive prioniodid, not sufficiently well represented to warrant specific reference. The posterior bar is thin and blade-like with fine confluence denticles. The fang is exceptionally compressed and is antero-posteriorly extended at its base. Beneath the fang is a small cup with slightly flaring lateral margins.

Figured specimens.—Univ. Missouri, C576–3.

Genus SYNPRIONIODINA Ulrich and Bassler

Synprioniodina sp. indet.

Plate VI, figure 1

Our Keokuk conodont collections contain incomplete denticulate bars that probably represent a species of *Synprioniodina*. The posterior bar is swollen at mid-height and merges orally into the base of long, slender, closely crowded to confluent, erect pointed denticles. Beneath the main denticle, which is directed slightly forward from normal to the bar axis, is a deep, elongate excavation that extends backward along the aboral edge of the posterior bar. Nature of the antero-inferior bar unknown.

Figured specimen.—Univ. Missouri, C576–4.

Genus SPATHOGNATHODUS Branson and Mehl

Spathognathodus deflexus Branson and Mehl, n. sp.

Plate VI, figure 6

Blade arched, thin, comparatively narrow, straight except for an inward bend of the lower posterior end back of the cup. Denticles small, compressed, confluent except for short blunt apices. Navel well back of mid-length, deeply excavated to a sharp point, outline elongate, chiefly anteriorly, with pointed extremities extending along the edge of the blade as a faint groove, lateral margins thin and laterally extended. Anterior terminus not known.

Holotype.—Univ. Missouri, C578–1.

Occurrence.—Keokuk, Sylvan Beach, St. Louis County, Missouri.

Spathognathodus regularis Branson and Mehl

Plate VI, figure 7

Spathodus regularis Branson and Mehl, 1938, Univ. Missouri Studies, vol. 13, p. 137, pl. 34, figs. 1–3.

The single specimen in our Keokuk collections referable to this species is not well preserved, but it agrees with *S. regularis* in its main features.

Figured specimen.—Univ. Missouri, C577–4.

Spathognathodus sp. indet.

Plate VI, figures 4, 5

A species, represented only by incomplete specimens in our Keokuk collections, has the general proportions of *Spathognathodus* (*Spathodus*) *pulcher* Branson and Mehl, but averages somewhat larger and has a less laterally expanded navel.

Figured specimens.—Univ. Missouri, C576–5.

PLATE

EXPLANATION OF PLATE VI

All figures slightly less than 30 diameters

Fig. 1. *Synprioniodina* sp. indet. Lateral view of posterior bar of a typical representative, Univ. Missouri, C576–4.

Figs. 2, 3. *Ozarkodina* sp. indet. Lateral views of two specimens, probably two species, Univ. Missouri, C577–3, C575–1.

Figs. 4, 5. *Spathognathodus* sp. indet. Lateral views of anterior and posterior ends of two specimens, Univ. Missouri, C576–5.

Fig. 6. *Spathognathodus deflexus* Branson and Mehl, n. sp. Outer lateral view of holotype, Univ. Missouri, C578–1.

Fig. 7. *Spathognathodus regularis* Branson and Mehl. Lateral view of imperfect specimen, Univ. Missouri, C577–4.

Figs. 8, 9. *Prioniodus* sp. indet. Lateral views of two incomplete specimens, Univ. Missouri, C576–3.

Fig. 10. *Ligonodina levis* Branson and Mehl, n. sp. Inner lateral view of holotype, Univ. Missouri, C574–1.

Figs. 11, 12. *Prioniodus cassilaris* Branson and Mehl, n. sp. Aboral view of fang and inner lateral view of holotype, Univ. Missouri, C575–2, C575–3.

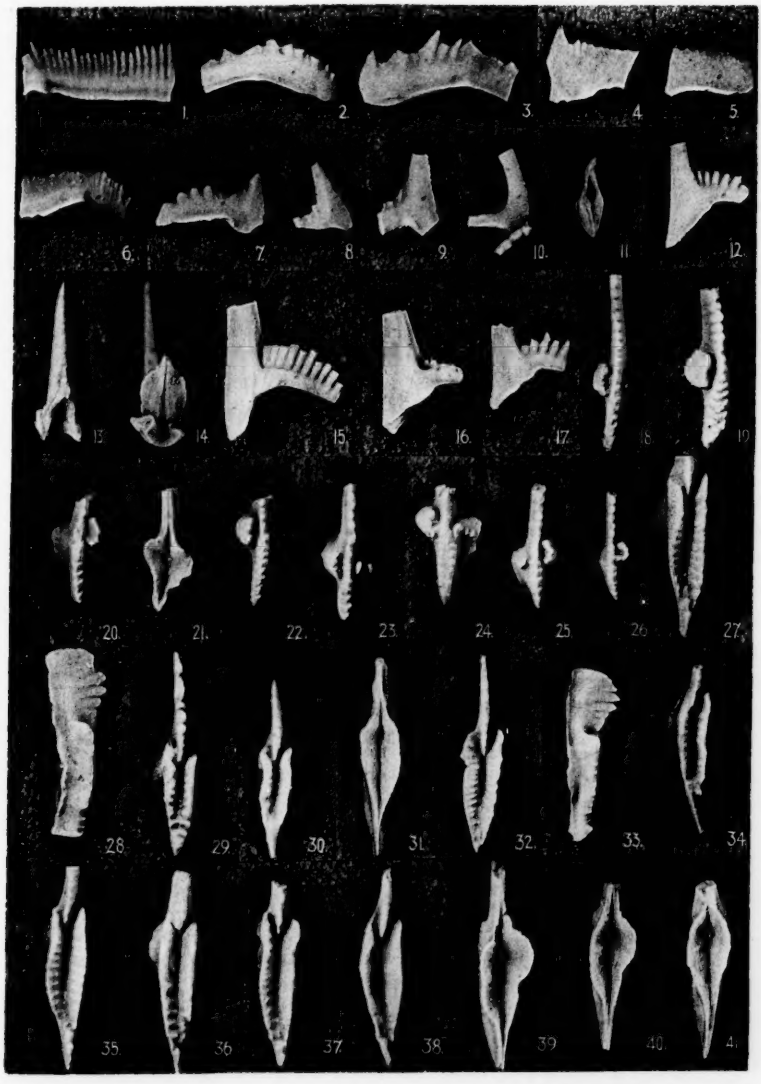
Fig. 13. *Trichognathus* sp. indet. Postero-aboral view showing nature of subapical excavation, Univ. Missouri, C578–4.

Fig. 14. *Hibbardella abnormis* Branson and Mehl, n. sp. Postero-aboral view of holotype, Univ. Missouri, C577–1.

Figs. 15–17. *Prioniodus cassilaris* Branson and Mehl, n. sp. Lateral view of three specimens showing variation in anterior outline, Univ. Missouri, C578–3 (fig. 15), C575–2. Figure 16 shows attachment scar in lateral view and may represent another species.

Figs. 18–26. *Gnathodus linguiformis* Branson and Mehl, n. sp. Oral and aboral views of nine specimens, Univ. Missouri, C574–5, C546–4 (holotype, fig. 19), C576–2 (figs. 20, 22, 26), C574–5 (figs. 21, 24, 25), C574–3.

Figs. 27–41. *Taphrognathus varians* Branson and Mehl, n. sp. Univ. Missouri, C574–4 (figs. 27, 35 38), C578–5 (holotype, fig. 28), C577–2, C579–1, C579–2, C575–4 (figs. 31, 33, 39–41), and C578–2 (a highly modified specimen from a Keokuk leak in the Burlington limestone at Calwood).



BRANSON AND MEHL CONODONTS FROM KEOKUK FORMATION

A RECORD OF TYPICAL AMERICAN CONODONT GENERA IN VARIOUS PARTS OF EUROPE

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Less then twenty papers have recorded conodont occurrences outside of North American and few of these have indicated any considerable variety. Excepting the "discovery" paper by Pander[1], Smith's[2] and Hinde's[3] papers on Scottish conodonts, Eichenberg's paper on the conodonts from the Culm of the Harzes[4], and Martens' descriptions of Devonian and Lower Carboniferous conodonts[5], none of these contains what may be considered a faunal assemblage from some stratigraphic unit.

A list of European genera of conodonts compiled from the literature is more confusing than helpful because it has been the custom of most European students to draw generic lines much more loosely than they are drawn by American students. An attempt at specific identification of forms from Europe is even more discouraging than generic classification.

On two occasions the senior author has collected many samples from various parts of Europe with the idea of applying the shale-washing methods that are prevalent in micro-fossil work in this country. He has paid particular attention to places where typical Devonian and Mississippian sections are exposed with

[1] Pander, C. H. 1856. Monographie der Fossilen Fische des Silurischen Systems der Russisch-Baltischen Gouvernments, pp. 1–91.

[2] Smith, John. 1907. On the occurrence of conodonts in the Arenig-Llandeilo formations of the southern uplands of Scotland. Glasgow Nat. Hist. Soc. Trans., v. 7, pp. 235–242, pls. 5–7.

[3] Hinde, G. J. 1900. Scotch Carboniferous conodonts, Glasgow Nat. Hist. Soc. Trans., v. 5, pp. 338–346.

[4] Eichenberg, W. 1930. Conodonten aus dem Culm des Harzes, Paleont. Zeitschr., B. 12, s. 177–182, 1 Taf.

[5] Martens, Hans. 1933. Neue Conodonten aus Devon und Unterkarbon, Senckenbergiana, B. 15, S. 12 22, 1933.

the idea that faunas of these periods would give the best opportunity to compare conodont faunas of the two continents. Although these collecting attempts met with little success they show the way to future possibilities and also emphasize the difficulties encountered by the worker in Europe in the investigation of conodonts.

Apparently there are few places in Europe where large areas of Paleozoic sediments, comparable to the Mississippian of the Mississippi Basin, are free from marked metamorphism. This seems particularly true for that type of regional metamorphism which is conspicuous in its effects on micro-organisms.

The conodonts figured by Schmidt[6] and by Eichenberg[7] are interpretations of natural molds and we find that our European collections, in contrast with those from the United States, show a large proportion of the specimens preserved in this way. Most of our material from both Devonian and Lower Mississippian of the Hartz Mountains shows either the delicate impressions of the conodonts alone or the conodonts themselves preserved as a soft clay- or chalk-like substance, too fragile to be isolated as a unit from the matrix. When such material is removed from the natural mold the latter is likely to be crossed by delicate partitions of matrix, the consolidated material that filled cracks across the original conodonts.

Empty conodont molds are clearly the result of solution and the clay residue, found in the molds, is an insoluble residue.

Elsewhere we have pointed out the surprising resistance of conodonts to the ordinary processes of chemical weathering during past geological times. This is surprising when it is realized that very dilute hydrochloric acid destroys them. Shales that are sampled where rootlets come in close proximity to conodonts commonly produce specimens that are deeply pitted with dull whitened zones surrounding the etched portions. On the other hand acetic acid seems to have no effect on conodonts, regardless of the concentration. It may be concluded that

[6] Schmidt, H. 1934. Conodonten-Funde in ursprunglichen Zusammenhang. Paleont. Zeitschr., B. 16, S. 76–85.

[7] Eichenberg, W., Op. cit.

beautifully preserved conodonts mean an impervious matrix or the general absence of vegetable acids in the ground water. The poor preservation of conodonts in many European localities may be interpreted as resulting from a hard pervious matrix and presence of acids of the harmful varieties.

We have been able to segregate from Lower Carboniferous shales obtained from the Hartz Mountains some remarkably well preserved molds of conodonts and a large number of badly broken specimens of conodonts, all showing the effects of weathering designated above.

A group of specimens collected by Branson at Hauern Feldweg über dem Clymenien Arker, Wildungen, Germany, is remarkably well preserved so far as substance is concerned. However, all specimens have been so badly shattered by closely spaced fractures that the largest part of a specimen consists of a short section with parallel broken ends. Some of these pieces show within themselves incipient or sealed parallel cracks. These specimens came from a quarry from which some of Stensio's[8] fishes were collected.

Very unlike these two types of preservation are some specimens from the unterer Hauptmuschelkalk at Neustadt bei Harblinger, contributed by Herr Karl Feifel. It should be stated here that there is some question about the geological occurrence of these specimens. However, granting that they came from the Muschelkalk, we do not consider that they are a record of Mesozoic conodonts, but of residue from Pennsylvanian or Permian formations. The specimens are beautifully preserved in the same manner as those from the Pennsylvanian of Central United States.

From these three collections a sufficient number of specimens have been segregated to identify with certainty several genera either hitherto unknown to Europe or not sufficiently well figured to make sure their relationship to American forms. Some of the Devonian specimens from Wildungen seem to have been reworked, and there is uncertainty about the Muschelkalk

[8] Stensio, Erik A. Son. 1934. On the heads of certain Arthrodires, K. Vet. Akad. Handl., ser. 3, 13 S. 3.

specimens mentioned above. The important point, as we see it, is that there is a much greater variety of conodonts in European sediments than the published records indicate; that some of these are so distinctive that they may be identified by fragmentary materials; that some of these forms have small time range; and that the possibility of moderately close wide-range correlation may be expected because there is great similarity, almost conspecific in some cases, between American and European diagnostic forms. Some of the forms are figured and described in the following paragraphs:

Genus ICRIODUS

Plate VII, figures 1, 2, 12, 14

Representatives of this genus have been reported from a variety of formations, wide-spread in the United States, but always Middle or Upper Devonian age, except in such cases as specimens have been reworked into the basal layers of some formation of later age. Worn specimens are abundant in the Bushberg (Lower Mississippian) of some localities of Central Missouri.

A single specimen (C64–5, U of Mo.) from the Devonian of Wildungen, Germany, too fragmentary to identify specifically, records this genus from outside of American for the first time. Its curved axis and the nature of the oral surface ornamentation place it near *I. curvatus* Branson and Mehl, the present known range of which is Upper Devonian.

Genus *Palmatolepis*

Plate VII, figures 3, 6, 11, 13, 15, 17

This genus we believe has not been correctly recorded previously outside of the Upper Devonian of the United States. Three specimens (C61–5, C62–5, and C63–1, U. of Mo.) representing two or possibly three different species of *Palmatolepis* come from Wildungen, Germany. The first of these is a section at mid-length of a slender sinuous form close to some of the more slender, elongate variations of *P. glabra* Ulrich and Bassler. The second is either a young individual of this species or more likely a new species comparable to *P. gracilis* Branson and Mehl.

The third specimen is very close to *P. delicatula* Branson and Mehl and may well be a senile representative of that species.

Genus DOLIOGNATHUS Branson and Mehl[9]

Plate VII, figures 25, 26

This genus is represented by species of great diversity, perhaps too great to be included in a single genus. Typical forms seem to be confined to the Lower and Middle Mississippian in the United States. One species, *D. lata*, has been found in the basal Sycamore as it overlies the Welden in southern Oklahoma and in the Lower Mississippian in southwestern Missouri. We have placed in this species a considerable variety which may ultimately prove to represent more than one form rather than differences from youth to old age and other legitimate variations as we now suppose. This species in its broadest sense, is recognized without question in delicately preserved natural molds from the series designated as unter Karbon by Martens[10] and Schmidt[11] in the Hartz Mountains of Germany. This species is the only representative of the genus which we have found in the material from the Hartz Mountains.[12]

Genus SCALIOGNATHUS Branson and Mehl[13]

Plate VII, figures 21–24

The genus *Scaliognathus* seems to have the same range as *Doliognathus*. *Scaliognathus* also includes a varied group most of which are so distinctive that they may be recognized in poorly preserved specimens. Representatives of one or more species of this genus were figured by Eichenberg[14] as *Prioniodus hercyincus*

[9] New and little known Carboniferous conodont genera. Jour. Pal., in press at time of this writing.

[10] Martens, Hans., Op. Cit.

[11] Schmidt, H., Op. Cit.

[12] Prof. H. Schmidt of the University of Göttingen kindly furnished us with fragments of the shales from the same locality that furnished the specimens described by him. He also directed Branson to a locality about four miles east of Osterode in the Hartz Mountains, but Branson found no conodonts.

[13] New and little known Carboniferous conodont genera. Jour. Paleontology in press at the time of this writing.

[14] Eichenberg, W., Op. Cit.

from the unter-Karbon of the Hartz Mountains. Of the thirty specimens described by Eichenberg five should be referred to *Scaliognathus* (16, 19–22), and others to *Polygnathus*, *Prioniodus*, *Hindeodella*, and possibly to *Bryantodus*. Very likely two specimens (24, 25) should be referred to *Gnathodus*. All thirty were considered parts of one species by Eichenberg.

Several clean cut natural molds from the unter Karbon of the Hartz Mountains duplicate in their major features several variants referred by us to *Scaliognathus anchoralis*. We have found this species only at or near the top of the Lower Mississippian, as defined by Branson,[15] and in the shales immediately overlying the Welden, the base of the Sycamore, in southeastern Oklahoma.

Genus GONDOLELLA Stauffer and Plummer

Plate VII, figures 7–10, 18–20

In its typical form *Gondolella* is too distinctive to be confused with other genera. Its known range is Lower Pennsylvanian to Lower or Middle Permian.

Several specimens referable to Gondolella were sent to us by Herr Karl Feifel of Stutgart, Germany. He records these specimens as from the Trochitenkalk, Unterer Muschelkalk at Neustadt bei Weiblungen.

Although these European specimens show little or no evidence of wear, we believe that they were contributed to the Muschelkalk as sediments derived from the weathering of Permian or Pennsylvanian rocks. It is possible that the collector incorrectly identified the strata from which the specimens were collected.

The specimens sent by Feifel are very close to one that is present in the upper Phosphoria (Lower Permian) of Wyoming. Ordinarily specimens from the two localities would be considered conspecific. Regardless of the doubt as to the exact age of the European occurrence it proves the existence of this genus in Europe and indicates possibilities of precise correlations when it is found in its normal faunal relationships.

[15] Branson, E. B. 1938. Univ. Missouri Studies, Vol. 13, No. 3, p. 5.

PLATE

EXPLANATION OF PLATE VII

All figures approximately 30 diameters

Fig. 1, 12. *Icriodus* cf. *I. curvatus* Branson and Mehl. Oral and aboral views of a broken specimen from Germany.

Figs. 2, 14. *Icriodus curvatus* Branson and Mehl. Oral and aboral views of two syntypes, Univ. Missouri C250–3, from the late Devonian of Missouri.

Figs. 3, 17. *Palmatolepis* sp. indet. Oral and aboral views of a large fragment from the Devonian of Germany comparable to the American form shown in fig. 6.

Figs. 4, 5. *Palmatolepis* sp. indet. Oral and aboral views of the mid-length section of a specimen from the Devonian of Germany, comparable to the American form shown in fig. 11.

Figs. 6, 11. *Palmatolepis* sp. Oral views of two specimens from the late Devonian of Missouri, for comparison with European specimens shown in figs. 3, 17, 4, 5.

Figs. 7–10, 18–20. *Gondolella* sp. Oral, lateral, and aboral views of seven specimens, apparently the same species. Figs. 7, 9, 10, 19, specimens said to come from the Muschelkalk of Germany. Figs. 8, 18, 20, specimens from the upper Phosphoria of Wyoming.

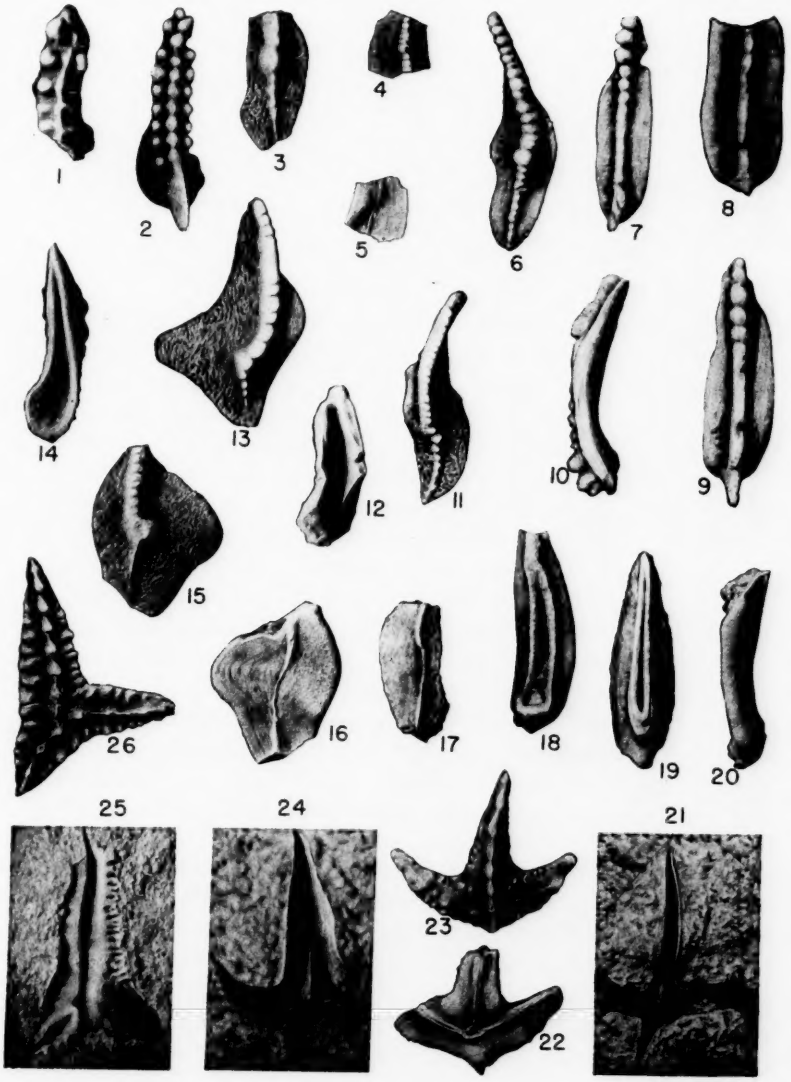
Fig. 13. *Palmatolepis glabra?* Ulrich and Bassler. Oral view of a specimen from the late Devonian of Missouri for comparison with figs. 15 and 16.

Figs. 15, 16. *Palmatolepis* cf. *P. glabra*. Oral and aboral views of a broken specimen from the Devonian of Germany.

Figs. 21, 24. *Scaliognathus*. Natural molds representing two species of this genus from Germany.

Figs. 22, 23. *Scaliognathus anchoralis* Branson and Mehl. Oral and aboral views of two specimens from the Mississippian of Missouri for comparison with figs. 21 and 24.

Figs. 25, 26. *Doliognathus*. Fig. 25, impression of the oral side of a specimen from Germany, similar to that in fig. 26. Fig. 26, oral view of *D. lata* Branson and Mehl, from the Mississippian of Missouri.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THE RECOGNITION AND INTERPRETATION OF MIXED CONODONT FAUNAS[1]

E. B. BRANSON AND M. G. MEHL

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Elsewhere[2] we have called attention to mixed conodont groups and have made an appeal for great care in selecting pure faunas when new assemblages are described. Since attention was first called to specific cases of faunal mixtures by us additional assemblages, presumably offered as pure faunas, have been described which, we believe, are made up of conodonts of markedly different ages. Under these circumstances we feel justified in emphasizing still further the occurrence of mixed conodont faunas and some of the problems they create.

Mixed faunas of mega-fossils are fairly common. Near Adamana, Arizona, fossils of both Pennsylvanian and Triassic age occur in the same member of the Chinle (Triassic) formation. Pebbles containing a considerable variety of fossils and also isolated silicified brachiopods and other large forms that were weathered from the Wells limestone have been found with Triassic vertebrates. The Wells fossils, regardless of their resistance, show unmistakable evidence of wear occasioned by transportation.

However, it is not so easy to detect abnormal stratigraphic associations of micro-fossils, of exceptional preservation such as silicification, which may minimize the marks of transportational abrasion. Morey[3] described an assemblage of ostrocodes from the basal sandy clay of the Bushberg and the assemblage was assumed to be of basal Mississippian age. At the time the paper was written little was known of the later Devonian ostrocodes and their occurrence in the Bushberg was considered as positive

[1] Read before the Geological Society of America at Minneapolis, Dec. 1939.

[2] Branson, E. B. and Mehl, M. G. 1933. Conodont Studies, Univ. Missouri Studies, vol. 8, pp. 10, 14, 15 and 265-267.

[3] Morey, Philip S. 1935. Ostrocods from the basal Mississippian Sandstone of Missouri: Jour. Paleontology, vol. 9, pp. 316-326, pl. 28.

evidence of the age although the formation contains many worn teeth of *Ptyctodus* evidently derived from the underlying Devonian rocks. Further investigations of the occurrence by James Keenan indicate that some, if not all, of the ostrocodes described by Morey are of late Devonian age. They are silicified and lasted through a period of weathering. R. E. Peck finds no other basal Mississippian Chara similar to the forms that he described from the Bushberg of the same locality as Morey's ostrocodes, and inasmuch as they are silicified, he does not insist that they cannot be of late Devonian age.[4]

In most cases of mixed faunas there are clues to the mixture in the actual marks of trituration or in special preservation that would account for the absence of such marks. It is probably because of this that the possibility of mixed conodont faunas has been ignored so generally. The conodonts are not hard and, theoretically, should show evidence of transportation if shifted considerable distances, unless they are exceptionally small or of a shape conducive to transportation in suspension.

In connection with Gunnell's statement of the evidence for the Fort Scott age of some of the central Missouri channel sands[5] (which, incidentally, we have not been able to verify) R. C. Moore, added the following, editorially:

"The possibility of redisposition of conodont material in the channel sandstones should not be overlooked. If conodonts are transported far they are likely to be somewhat broken and worn but otherwise they may show little effect of transportation."

In brief, without having been so expressed, it seems to have been assumed that mixtures of conodonts are likely to involve an appreciable degree of transportation and therefore some marks of this experience. In as much as conodonts are highly soluble in weak hydrochloric acid it has been natural to suppose that the chemical weathering of sediments would eliminate the possibility of conodonts in residual mantle. It follows then that unworn conodonts of average size would be assumed to be indigenous to the rocks in which they were found.

[4] Personal Communication.

[5] Gunnell, Frank H. 1931. Conodonts from the Fort Scott Limestone of Missouri: Jour. Paleontology, vol. 5, pp. 244–252, pl. 29.

It is our purpose to emphasize the importance of the introduction of residual conodonts into sedimentary accumulations of a later age and also to indicate other possibilities in the origin of mixed conodont faunas.

STRATIGRAPHIC ADMIXTURES

A type of mixed faunas, designated by us as stratigraphic admixtures, is widespread in occurrence and difficult to detect because the evidence for the admixtures lies in the knowledge of conodont successions rather than in field evidences. This type is the inclusion of an earlier assemblage of conodonts in the sediments and faunas of a later age.

In a forthcoming publication on Middle Ordovician conodonts from Oklahoma we figure four faunal groups, one from McLish, two from the overlying Bromide, and the fourth from the lower Viola of the same region. Each of these is very distinctive but the two Bromide assemblages show unmistakable contributions from earlier sources. The lower of the two has a few specimens that are typical from the underlying Bromide zone.

In central Missouri, near Browns, Boone County, a basal Mississippian sandstone (Bushberg) contains, in addition to its own characteristic conodont fauna, a large number of rounded conodont fragments. Many of these cannot be determined generically, but some are sufficiently distinctive to be recognized as typical upper Devonian forms.

Many illustrations of this sort could be cited, all of which give evidence of admixture through the worn condition of some of the specimens, but evident admixtures involving transportation without observable wear are also known.

Through the kindness of K. Feifel, of Stuttgart, Germany, we have received a collection of conodonts said to come from the Unter Hauptmuschelkalk, Trochitenkalk zone at Neustadt bei Weiblingen. Although the species is not identical with any of the American forms it is clearly of the genus *Gondollela* and resembles closely forms that occur in the Lower Pennsylvanian series of Missouri and Kansas and Permian of Wyoming. This is not to be interpreted as a range of Pennsylvanian

conodonts into the Muschelkalk, regardless of the fact that the specimens give no evidence of wear. On the other hand it may not be a valid illustration of stratigraphic admixture. It is possible that in this case the stratigraphic horizon of the European find has been misidentified.

Such occurrences as the last cited seem comparatively rare and, therefore, do not often confuse the faunal picture. A much more common and troublesome admixture consists of the incorporation of conodonts of one age with the basal sediments in an immediately overlying formation. In many cases this is accomplished without the slightest evidences of weathering on the earlier conodonts.

Elsewhere[6] we have cited several cases where two faunas, or even three, of entirely different age have been mixed and all included within a very limited zone. We have indicated that conodonts are remarkably free from destruction or deterioration by chemical weathering that seem to affect other microforms such as calcareous foraminifers and ostrocodes, an immunity that makes possible the retention of conodonts in a residual mantle for a very great length of time.

So resistant to chemical weathering are the conodonts that they may be segregated from calcareous scrap with acetic, citric, tartaric, and similar acids without dimming their surface gloss. In recent months we have segregated conodonts from many limestones of various ages by digesting the calcium carbonate with acetic acid.

On the north bluff of the Merrimac River at Castlewood, in St. Louis County, Missouri, Bushberg (basal Mississippian) sand stone in some places directly overlies the Maquoketa (Upper Ordovician) shale with a small thickness of Grassy Creek (Upper Devonian) shale intervening at other places. Practically every sample taken from the base of the Bushberg contains conodonts typical of the Bushberg and also well-preserved Ordovician and Devonian conodonts, regardless of the immediately underlying formation.

Perhaps the principles involved are more clearly evident at

[6] Branson, E. B. and Mehl, M. G., Conodonts from the Bushberg sandstone and equivalent formations of Missouri, Univ. Missouri Studies, vol. 8, pp. 265-267.

Brickeys in the Mississippi River bluff, Ste. Genevieve County, Missouri. Here the Chouteau (Fern Glen) limestone seems to rest on the Maquoketa, but intervening is a member about four inches thick that is somewhat lighter in color than the Maquoketa shale beneath, has poorer bedding, and is sandy. In this thin member are well-preserved conodonts from Maquoketa, Grassy Creek, and Bushberg formations. It seems evident in the absence of worn conodonts that the weathering of the shale in post Maquoketa time left a residuum containing a concentration of Maquoketa conodonts. This mantle was reworked by the advancing Grassy Creek sea to become the first layers of this epoch and to record also the conodonts of that time. Again, a post Devonian weathering left a mantle in which both Maquoketa and Devonian conodonts formed a part. This material became part of the first beds in the Bushberg sea, which added its conodont fauna. Apparently this portion of the Bushberg deposit was swept free of residual material upon the next sea advance for there is no evidence of Chouteau conodonts beneath the first limestone layers that represent this formation.

Another illustration of stratigraphic admixture is the remarkable abundance of Lower Ordovician conodonts in association with Devonian forms. On the bluff of the Missouri River near Providence, Missouri, are irregular pockets of dark sandy clay underlying the Cooper (Middle Devonian) limestone and resting in irregularities in the top of the Jefferson City (Lower Ordovician) dolomite. The conodonts in these thin scattered patches are about equally divided in numbers between Jefferson City and Cooper forms.

A cursory examination of some of the faunas that we believe to be admixtures of conodonts of different ages listed in publications, will indicate the confusion likely to result if admixtures are not recognized.

CONODONTS OF THE GLENWOOD BEDS

As stated by Stauffer[7] the Glenwood beds in the Upper Mississippi Valley lie between the St. Peter sandstone and the Platte-

[7] Stauffer, C. R. 1935. Conodonts of the Glenwood Beds, Bull. Geol. Soc. Amer., vol. 46, p. 125.

ville limestone. There is little question of the correlation of the Platteville with the Plattin limestone of eastern Missouri, the conodont fauna of which was described by us in 1933.[8] It is evident that between the St. Peter and the Plateville there is a large stratigraphic break, unless the St. Peter of Minnesota is very much younger than that of Missouri, with only the Glenwood to occupy this interval. Other than the Glenwood there is nothing to represent the lower Joachim or Dutchtown and the Joachim proper. It is our belief that the Glenwood does not represent any part of this interval but is part of the Platteville as recognized by the U. S. Geological Survey and the Kansas Geological Society Conference Report of 1925.

Stauffer stated that among the Glenwood conodonts there are two distinct elements, one typical of the Harding of Colorado and the other of the Plattin, and that conodonts of an intermediate age (the Joachim) are almost completely lacking.

"The total known species of Glenwood conodonts is between 85 and 90. In many ways it is a remarkable assemblage. Perhaps the most striking feature is the presence of the delicate, sharp-pointed, hand-like crests with the fibrous structure, which so closely resemble forms from the Harding sandstone of Colorado. Scarcely less remarkable is the lack of nearly all trace of the distinctive Joachim conodont fauna, which, in Missouri, occurs in beds overlying the St. Peter sandstone. Only a few doubtful specimens suggest that horizon, and these can just as easily be compared with species definitely from the Plattin, or Platteville, fauna. This is suggestive, for the Joachim lies on the St. Peter sandstone, and the Glenwood, occupying a similar position, is usually regarded as a transition zone from the St. Peter to the Platteville (Plattin)."

"The most abundant species of Glenwood conodonts are those resembling, or identical with, Platteville and Decorah species. Thus, there appear to be two elements of the fauna, occurring together, and inseparable in the field."

Stauffer considered the suggestion that the conodont fauna is mixed, but made no attempt to segregate the two groups. He discussed the possibility of admixture as follows:

"The land area and the derived fossils may have been of St. Peter age, but the Glenwood sea was filled with Middle Ordovician life, and most of its fauna is of that age. Basal Glenwood sediments may be largely of St. Peter origin, and the

[8] Branson, E. B. and Mehl, M. G. 1933. Conodonts from the Plattin (Middle Ordovician) of Missouri, U. of Mo. Studies, vol. 8, pp. 101–119, pls. 8–10.

bottom of the formation too intimately mingled with the loose sands derived from the older beds to allow a definite contact to be drawn between it and the St. Peter, but the fossil-bearing Glenwood beds belong in the Mohawkian series, and are not much older than the Platteville limestone."

We find that *Chirognathus*, one of the important forms in the Glenwood, is typically and abundantly developed in the lower Middle Ordovician. Its occurrence in the middle part of the Middle Ordovician is very rare. On the other hand *Oistodus* and *Paltodus*, also abundant in the Glenwood, do not seem to overlap the *Chirognathus* fauna but follow it with an appreciable intervening time. The McLish of Oklahoma has a *Chirognathus* fauna with no representatives of *Oistodus*, *Paltodus* or *Phragmodus*. Our next producing zones above this are two members in the Bromide (the Tulip Creek is missing). The lower of these contains a few worn specimens of *Chirognathus* but neither this nor the succeeding zone introduces the typical Plattin fauna. The lowest Plattin forms are in the base of the Viola, where *Oistodus*, *Phragmodus*, *Paltodus*, and *Dichognathus* are abundant.

THE NEW ALBANY SHALE

Another illustration of stratigraphic admixture, judged from the published list of conodonts concerned and from our collections and study of the specimens described, is in the band designated by Huddle[9] as the upper conodont producing zone of the New Albany shale of Indiana. This he describes as a zone from 0 to 10 feet thick beneath the Rockford formation, the major part of which, judged from Huddle's columnar sections and descriptions, consists of black fissile shale. Huddle recognizes as of Rockford age a gray-green shale, up to a foot in thickness, that immediately underlies the massive dense gray-green mottled Rockford limestone, and therefore does not intend to include this in the upper New Albany.

In discussing the age of the upper New Albany zone Huddle concludes that it is most likely Devonian, but recognizes the conflicting evidence afforded by one of the conodonts which is

[9] Huddle, J. W. 1934. Conodonts from the New Albany shale of Indiana, Bull. of Amer. Paleontology, vol. 21, pp. 1–114, pl. 1–12.

also found in the Welden, and the presence of a Kinderhook fish, *Cladodus springeri*, in this member.

An analysis of the fauna of Huddle's upper conodont zone assemblage in the light of our report on the Bushberg (basal Mississippian) conodonts, which appeared a short time before Huddle's publication, suggests a very different relationship of this zone and its parts.

Of the 81 species from the upper zone as listed by Huddle, 55 are confined to this zone. The other 26, with few exceptions, belong to genera which are not particularly diagnostic. We believe that there is as yet too much variation in specific delineation amoung investigators of conodonts to give much meaning to species distribution except in special cases. For this reason an analysis of the 55 species mentioned above does not seem profitable except as they represent fairly well established genera of diagnostic value. The following genera, with representative species from Huddle's list from the New Albany in parentheses, are unknown to us above the Devonian except as they are mixed from residual or transported mantle from Devonian rocks:

Icriodus.....(*Gondolella? nodosa* Huddle)
Ancyrodella.....(*Polygnathus rotundiloba* Huddle)
Ancyrognathus.....(*Palmatolepis? inequalis* Huddle)
Palmatolepis.....(*Palmatolepis perlobata, minuta* and other species)
Polylophodonta.....(*Polygnathus gyralincata* Huddle)

It will be noted that none of the forms listed above, with the exception of *Palmatolepis minuta* Huddle, is recorded from his upper zone. On the other hand, Huddle lists from the upper zone several genera which we have never found in a pure fauna older than the Bushberg (basal Mississippian). All representatives from the New Albany, in the following list taken from Huddle, are from the upper zone.

Pseudopolygnathus.....(no species recorded)
Pinacodus.....(no species recorded)
Siphonognathus.....(*Polygnathus newalbanyensis, P. plana*)
Solenognathus.....(*Bryantodus camurus, B. microdens, B. plexus*)

Through the kindness of Professors Cumings and Galloway we have had the opportunity to study Huddle's types. We have

also made collections from the three zones in the New Albany with Huddle's register of localities as a guide. As a result of these investigations we cannot record a typical Mississippian form from any part of the New Albany that is represented by black fissile shale. On the other hand, our collections from the zone between the fissile black shale and the massive Rockford limestone produce well-preserved and typical Bushberg conodonts.

In the light of our collecting experience in the sub-Rockford zone, we interpret Huddle's transgression of the upper zone by one typical Devonian genus and several nondiagnostic species that are recorded in both the upper New Albany and the middle or lower zones of this formation, as follows:

First: a general paucity of conodonts in the hard fissile black shale of the upper New Albany such that the actual number of genera and species in that unit is small.

Second: Huddle seems to have included in the upper New Albany what appears to be a variable but always small thickness of highly weathered, comparatively soft, upper part of the fissile black shale. We believe that this is the residuum of the weathered black shale developed in pre-Rockford time and reworked with the first advance of the Mississippian sea. This residuum seems to have had few New Albany conodonts so that the Bushberg fauna is nearly pure. Whether the yellowish green shale that immediately underlies the Rockford limestone is the initial phase of the Rockford or a separate faunal unit remains to be determined, perhaps by the discovery of a Rockford conodont fauna.

Third: Most, if not all, of the actual stratigraphic mixture that appears in Huddle's upper New Albany is the result of the inclusion in that zone of some specimens from the shale along with those collected from the zone that appears to be weathered black shale but is really the reworked residuum from the New Albany.

Huddle's zonal collecting, his exact recording of types, and his good illustrations and descriptions make it possible to separate with fair certainty his list of New Albany species into New

Albany (Devonian) and Bushberg (Mississippian). We cannot commend too highly his careful work on this fauna.

THE BASAL WELDEN FAUNA

In a recent paper by Cooper on the conodonts of the "Bushberg-Hannibal" horizon in Oklahoma[10] he lists 256 species of conodonts grouped in 34 genera, all from a zone of shale about a foot thick that lies between the Welden limestone and the Woodford formation. He correlates this shale band with the Bushberg-Hannibal because 63 of the 105 previously described conodonts in his list are found in the Bushberg or Hannibal. It is significant that in his correlation of the Mississippian formation of Oklahoma, Missouri, and Texas, Cooper places the Glen Park, Louisana, and Grassy Creek of Missouri in the Lower Mississippian. No reason is given for ignoring the evidence that seems to have placed these formations definitely in the Devonian, with the Bushberg marking the base of the Mississippian. Cooper likewise ignores the evidence presented by Huddle for the Devonian age of the lower Middle and most of the upper New Albany shale, which most stratigraphers believe is upper Devonian.

In a later paper we shall present the evidently pure fauna of the Welden limestone as it was obtained from the midthickness of this massive unit a few miles south of where Cooper seems to have collected most of his materials. (He gives no register of samples or localities for the species described.) When allowances are made for variations in specific identifications and such differences as go with a clear water as opposed to muddy water environment it will be seen that with the elimination from Cooper's list of all Welden species there is left a typical Bushberg-Hannibal conodont fauna with very few additions to the previously published lists except a few forms that are typical of the Woodford. It should be added that there is little in the Welden that is not also present in the assemblage presented by Cooper. There is much to indicate that the Welden fauna is as young as Middle Mississippian and it seems certain that the typical

[10] Chalmer L. Cooper. 1939. Conodonts from a Bushberg-Hannibal horizon in Oklahoma, Jour. Paleontology, vol. 13, pp. 379–442, pls. 39–47.

middle and upper Lower Mississippian faunas are missing in the Welden.

In the light of this evidence one must conclude either that the sub-Welden shale contains a mixed fauna, Bushberg and Welden, or that the Bushberg of south Central Oklahoma is equivalent to not only the Bushberg of Missouri but also to the Chouteau in its broadest sense and probably the Burlington and the Keokuk as well. In the latter case the necessary assumption that the south central Oklahoma Bushberg was shut off from the areas of typical late Lower and Middle Mississippian conodont development does not satisfy the requirements, for typical Welden conodonts are found in the lowest part of the sub-Welden shale.

THE CEDAR VALLEY

In a recent paper Stauffer has described conodonts from shale partings in the Cedar Valley limestone (Devonian) of Minnesota and the same fauna with an admixture of Ordovician conodonts from clays resting on the Cedar Valley.[11] He suggests that the clays in which the mixed fauna is found is probably of Cretaceous age.

No direct age analysis is given of this mixed fauna, but in the discussion of the genus *Acodina* Stauffer the inference is that its representatives are of Devonian age.

> "The genus (Acodina) includes those forms from the Olentangey shale described as *Acodus formosus*, *Acodus inopinatus*, and *Acodus zionensis*. It seems evident that the genus *Acodus* probably should be restricted to Ordovician, possibly to Ozarkian forms and not be required to include those without keels on their inner and outer faces. The general appearance and structure of these forms makes it seem desirable to choose a generic name close to that of Pander's term."

All species of the genus *Acodina* described by Stauffer are recorded as from the Cretaceous clay above the limestone along with many typical Ordovician forms. Under these circumstances the assignment of species of *Acodina* to the Devonian is based only on the similarity to forms reported from the Olentangey. Many specimens assignable to the genus *Acontiodus*, as we have

[11] Stauffer, C. R. 1940. Conodonts from the Devonian and associated clays of Minnesota, Jour. Paleontology, vol. 14, pp. 417–435, pls. 58–60.

segregated them from green sands of the Narvic region of Estonia, from which Pander's conodonts came, show remarkable similarity to species of *Acodina* described by Stauffer. Some of Stauffer's specimens resemble closely an undescribed species of *Acontiodus* from the Kimmswick of Missouri.

We are inclined to believe that any record to date of simple cone conodonts in sediments younger than Silurian constitutes evidence of mixed faunas or fragments, unrecognized as such, from more complicated forms. This does not preclude the possibility of a higher range for the simple forms for it must be remembered that nothing has been published concerning the conodonts of the interval between the Middle Silurian and the Middle Devonian.

STRATIGRAPHIC LEAKS

One of the more common of the various types of mixed faunas results from what we have designated as "stratigraphic leak"—the introduction of conodonts of one age into association with beds of an earlier time.

In a quarry in the Bowling Green limestone (Silurian), near Bowling Green, Missouri, are green bands of clay that cut across the massive beds of limestone and extend between the beds at various levels. These bands clearly represent filled solution channels in the limestone. It might be assumed that the material of the fills was derived from the limestone itself or that the clay came from higher zones. Although not overlain by the Grassy Creek (Devonian) at this particular spot, this formation normally overlies the Bowling Green in this region. Repeated sampling of the clay bands here described has produced many conodonts, all of Grassy Creek age.

On Missouri State Highway No. 19, about 6.5 miles south of the junction with U. S. Highway No. 40, in Montgomery County, are irregular clay filled channels in the Joachim (Middle Ordovician). In some of these well preserved conodonts of both Ordovician and Lower Mississippian age have been found. Many clay patches show no connection with the Lower Mississippian although cavities extend across bedding planes. The

normal succession in this region is Joachim, Plattin, a considerable thickness of Devonian, and Lower Mississippian. At the present time Plattin limestone is the youngest formation present in the vicinity of one of the most productive stringers, one in which both Joachim and Bushberg (basal Mississippian) conodonts are associated.

Following Mississippian deposition in Central Missouri, prolonged erosion developed a system of surface stream channels of varying depth in which the coarser residual materials were deposited by an invading Pennsylvanian sea, to become an irregular sandstone at the base of the Pennsylvanian system. Beneath the flat interstream areas of the pre-Pennsylvanian surface there was developed a system of caverns of markedly variable size, and many irregular underground laminar channels between the limestone beds. For the most part these caverns and channels were connected directly with the surface, either through enlarged joints or sink holes of the typical collapsed cavern type.

The obvious infiltration of early Pennsylvanian sediments into some of the channels in the Burlington suggests that some of the clay bands between the beds of Burlington limestone are also leaks from the Cherokee, the formation immediately succeeding the basal Pennsylvanian sandstone. For this reason, although we have not found Pennsylvanian conodonts in them, we have not ventured to suggest that the conodonts found in them are of Burlington age.

In the collapse of the roof of some of the caverns in the Burlington large slabs of Keokuk limestone and shale were dropped below the level of subsequent truncation, to witness the former presence of the Keokuk in the area that later presented a denuded Burlington surface to the first advance of Pennsylvanian seas. It is not surprising, in the light of these events, to find stringers within the Burlington that contain conodonts of Keokuk age. Recent discovery of conodonts in the limestone proper of the Burlington, and the finding of conodonts elsewhere in sections of undisputed Keokuk age, make it possible to pronounce some of the conodont occurrences in the Burlington as Keokuk leaks.

Green clay bands, low in the Burlington in an old quarry near Calwood, Callaway County, Missouri, have produced a fair abundance of conodonts that are identical with those of a splendid Keokuk fauna found in another part of the state.

As a rule, such bed-like clay introductions either cut across beds, are connected with stringers that cut across beds and extend toward the surface, or form an irregular body that is not to be mistaken for true bedding.

Another source of stratigraphic leak, less evident and less common, perhaps, seems to result from the subsurface weathering of limestones, and the contribution of their conodont content to the top of underlying shales or clay partings. In our attempts to determine possible zonal distribution of conodonts in the Cherokee we found that, commonly, a thin band of greenish-yellow clay at the top of a dark blue shale that immediately underlies the massive upper Fort Scott limestone is highly productive of conodonts. This clay band seems to represent weathered shale in part and in part insoluble residue from the base of the overlying lime. It is evident that in many places ground water has descended through the limestone series along vertical joints and has moved laterally along the upper surface of the underlying shale. In this lateral movement the under surface of the limestone has been channeled in places and in some cases seems to have been materially thinned by solution. Although we cannot cite actual illustrations of real mixed faunas through such processes, there is reason to believe that there has been an abnormal distribution of numbers and proportions of conodonts in the case described above. Likewise, there is little reason to doubt that limestone might contribute conodonts to an underlying formation of a distinctly different age. The effectiveness of the process depends on the abundance of conodonts in the limestone and their ability to withstand the attack of solvents.

PHANTOM FORMATIONS

We see in the sub-Welden conodont group cited above not only an outstanding case of a mixed fauna, but also an illustration of what may be called a phantom formation. Certainly, if

Welden conodonts were incorporated in the sub-Welden clay at a time much later than Bushberg, this clay is of Welden age and not Bushberg. On the other hand it is scarcely conceivable that such a large number of beautifully preserved, delicate Bushberg conodonts could survive the trituration of long transportation to the Welden locality. Their presence seems to testify to the former existence of the Bushberg in this area and to the remarkable resistance of the conodonts to chemical weathering which permitted them to remain as part of the insoluble mantle formed before the Welden sea invasion.

INTERPRETATION OF MIXED FAUNAS

The evidence of stratigraphic leaks and stratigraphic admixtures might be considered as detracting from the usefulness of conodonts in close stratigraphic determinations, but we do not so consider it. One may as well argue that drill cuttings are of little value because each sample is likely to contain materials from a younger unit. It would seem that the logical interpretation of any conodont assemblage is the reverse of that used in studying well cuttings. It is the youngest group of conodonts that fixes the age of the fauna rather than the oldest materials present, as in the case of the cuttings.

DENISON SCIENTIFIC ASSOCIATION

Organized April 16, 1887

REPORT OF THE PERMANENT SECRETARY FOR THE YEAR 1939–1940

Officers serving the Association during the current year were
A. C. LADNER, *President*
F. G. DETWEILER, *Vice-President*
W. C. EBAUGH, *Permanent Secretary and Editor*
GEORGE D. MORGAN, *Recording Secretary and Treasurer*
L. E. SMITH, *Librarian*

In accordance with long-established custom, meetings of the Association were held alternate Tuesday evenings in the lecture room of the Department of Physics, Barney Science Hall, except as noted in the reports following.

October 3

THE WORLD OF TOMORROW: THE NEW YORK WORLD'S FAIR. HORACE KING.

In the glittering modernistic buildings which flank the beautiful parkways one finds soberly instructive and fascinating industrial exhibits, magnificent collections of historical and modern paintings, state and foreign pavilions, and freak and peek shows of the immense amusement area. For sheer size the most impressive monuments are the now famous Trylon and Perisphere, the George Washington of Constitution Hall, and the Stalin's Worker and Star atop the Russian Building—symbols of the confusion of objectives and themes which seems to have pervaded the Fair program. The present Fair, only five years from Chicago's Century of Progress, must inevitably invite comparisons. Can either of them be considered as a true index of American culture? Can they have any far reaching constructive

influences upon our way of life? These questions provide adequate grounds for discussion.

October 17

EVOLUTION TODAY. A. W. LINDSEY.

Even scientists have fads, such as the prevailing use of the term "speciation" in serious scientific discussions. But this disguise only veils, without concealing, the fact that studies in evolution are still being pursued in biology. The last upheaval centering around the subject was the well-known Scopes trial at Dayton, Tennessee. Tracing the story of evolutionary thought from the time of Darwin's "Origin of Species" (1859), with its conflicts theological and scientific, through the works of de Vries, Mendell, Weissmann, and the most modern geneticists, the importance of experiments upon plants and animals was emphasized and the as yet unsettled problems of causation of mutations, transmission of special characteristics, etc. were discussed.

October 31

COLOR IN LIGHT. JESSE SKRILETZ.

The history of stage lighting from the time of the Greeks and their outdoor theatres, through the renaissance to the most modern installations of today, was followed by a presentation of the theories of color and light, association of ideas with color, general and special lighting, illusions rather than reproductions in light effects, and methods of electrical control of the lights themselves. Demonstrations of effects produced by color additions and subtractions made vivid the solutions of problems in stage lighting.

November 14

THE DISTRIBUTION AND DETECTION OF METEORIC IRON IN THE EARTH. LINCOLN LA PAZ (The Ohio State University).

Having worked out a mathematical solution for the problem of probable meteorite distribution, and devised a method for

locating these iron visitors from interstellar space, the exploration trip of 15,000 miles extending from Ohio to the southwestern extremity of the United States was described in some detail. Adding considerably to the interest of the address were many illustrations showing field work of the expedition, and specimens of meteorites recovered from sites located by the instruments used for the purpose.

November 28

PLANT PATRIARCHS: THE BIG TREES OF CALIFORNIA. MALCOLM E. STICKNEY.

When we consider the span of life among the creatures of the earth, we are impressed with three outstanding facts: (1) that this span varies widely in different organisms, from about a few hours in some of the insects to 300 years for certain reptiles; and from a few weeks in some of our spring flowers to thousands of years in certain species of trees; (2) that where the lamp of life burns fiercely it is likely to go out early—the long-lived organisms are, for the most part, those that travel slowly along life's pathway; (3) that in the case of almost any species there may appear now and then individuals that live conspicuously beyond the normal life span. Among these Methuselahs are the Big Trees of California. Trees have an advantage over other living things in longevity, for while a tree may live for hundreds of years in some cases it is only the sap wood, along with the cambian and a little of the bark, that contains living cells. The bulk of the heart wood consists of dead cells, and can function in the life of the plant only by supplying mechanical support. It is therefore merely the outer part of the tree that is truly alive, a region that spans only a few years, and not the centuries that represent the total age of the tree. Many of these old trees were described and illustrated, and the part played by climate in their growth—as well as in contemporaneous human history—was explained from the ring records of the trees themselves.

December 12

ADSORPTION AND CRYSTAL HABIT MODIFICATION.

WESLEY C. FRANCE (The Ohio State University).

Relationships between the colloidal and crystalline states of matter, the methods for determining crystal structure, the application of theoretically deduced processes for influencing the forms crystals will assume, and the probable uses of such information in industry, were discussed. Illustrations, models of molecular and crystal aggregations, and crystals themselves formed under predetermined conditions, rounded out the theoretical part of the lecture.

January 16

COSMIC RAYS. LEON E. SMITH.

Starting with a description of ionization chambers, cloud chambers, and Geiger-Müller counters, their construction and use, it was shown how the effects of cosmic rays are detected and measured even though the rays themselves have not been explained satisfactorily, Millikan's claims that they are very penetrating radiations with wave lengths much shorter than X-rays, and Compton's explanations on the basis of a particle nature, were contrasted, and the experimental foundations for each theory presented. Even after ten years of work the source of cosmic rays has not been determined, nor have reasons been forthcoming to explain the variations in their occurrences, apparent cycles of frequency, and relationships to atomic disintegration or formation.

February 6

COMPARATIVE PSYCHOPATHOLOGY. LYNDE C. STECKLE.

Ever since the rather fortuitous development, by one of Pavlov's students, of "experimental neurosis" in lower animals, numerous studies have been made in what might be called "comparative psychopathology." The reasons for this stem from two

sources of interest: (1) the appearance of behavior in lower animals formerly regarded as obtaining only the human; (2) the unsettled status of abnormal psychology and psychiatry. It is manifestly impossible to study the course of abnormal behavior in man. Conditions of the appearance and disappearance of psychopathic behavior in the human cannot be controlled adequately. The rat, however, is in no position to express such objections, consequently its life cycle can be interfered with at the whim of the investigator. That the rat may exhibit many of the patterns characteristic of human breakdown has been demonstrated abundantly, but the extent to which it is justifiable to compare specific detailed infra-human and human maladjustment is a question for time and experiment to decide. When the total process of experimentally produced behavior-breakdown in lower animals becomes understood clearly, then psychiatry may expect greater and greater contributions from this field; at present, however, the phenomena involved constitute a highly interesting laboratory experience.

February 20

PHOTO-ELASTICITY. C. S. ADES.

Within a relatively short period of time—practically during the past ten years—a new method has been developed for research and investigational work on engineering materials. A model of special transparent material is placed in a polariscopic field where it is subjected to a load and to a special type of light. The result is a visual image containing alternate bright and dark bands of light, the bands bringing out clearly the actual lines of stress in the model. It is assumed, of course, that the latter acts similarly to its prototype. Using such a model it is possible, by fairly simple mathematics, to obtain a close approximation to the actual stresses in, say, a building material or a machine part. Development of the formulas concerned was followed by a demonstration with actual models of the processes described.

March 5

RECENT ADVANCES IN ASTRONOMY. FREEMAN D. MILLER.

(1) An illustrated account of the 200-inch telescope in California, now nearing completion, was given. (2) In the summer of 1939 the planet Mars was unusually close to the earth, and an expedition was sent to the southern hemisphere by the Lowell Observatory to obtain observations under the best possible conditions. Hundreds of photographs were made which seem to confirm the existence of many of the puzzling markings sometimes called "canals" which have long been a subject of dispute among astronomers. (3) "Super-novae" are stars which suddenly explode into brilliance a hundred-million times that of our sun. Since this class of star has been recognized only recently, little is known of the subject, and the explanation of these cosmic cataclysms offers a fascinating field for speculation.

March 19

MYSTERIOUS CRATERS OF THE CAROLINA COAST. DOUGLAS JOHNSON (Columbia University). A Sigma Xi Lecture. Granville Opera House.

The coastal plain of the Carolinas is dotted with many thousands of oval depressions called "bays," occupied by marshy forests and frequently bordered by low rims of sand. These peculiar depressions have been interpreted as craters produced by the impact of a giant shower of meteorites striking the earth obliquely in a northwesterly direction. There are difficulties confronting the acceptance of this or any other interpretation of their origin. The search for a satisfactory explanation of such unusual features of the earth's surface affords an excellent opportunity for demonstrating methods of scientific investigation. By the use of many pictures of the features involved, and a painstaking review of the steps followed in reasoning out probable causes from the observed results, an entirely new explanation of the origin of the craters was proposed.

April 9

MODERN LIGHTING PRACTICE. KURT FRANCK (The Holophane Company).

An outline of the theoretical basis for modern lighting practice was followed by applications of these deductions to such important fields of modern civilization as the home, radio, and aviation. Experimental demonstrations showed the benefits derived from the proper control of light in the home.

April 23

THE STATE OF OHIO AND ITS RELIEF PROBLEM. WILLIAM HARTSOUGH (The Department of Public Welfare of the State of Ohio).

As long as America was essentially an agricultural country the doctrine of local responsibility for relief worked fairly well. After the industrial era was under way, and cities grew tremendously, a change occurred: no marked alteration in relief methods was introduced until the breakdown of 1929 took place, but then taxation on a large scale for this purpose had to be introduced. The legal set-up with reference to local, state and federal participation in relief work was presented, some idea as to the amounts involved was given, and the conclusion drawn that relief has become a permanent function of government. The reasons for this are (1) the breakdown of family and group loyalties; (2) the immense number of unemployed, variously estimated at nine to twelve million potential wage earners; and (3) the lengthening of life expectancy from 49 to 61 years within a generation, thus adding many older persons to the labor market.

May 7

OHIO LANDSCAPES. FRANK J. WRIGHT.

An illustrated, non-technical address upon the typical landscapes of the State of Ohio showed the great divisions into the Allegheny plateau and the interior lowlands, the petrological make-up of the rocks, the probable causes of the physiographic features now observed, and the great influence of glacial action in determining present landscapes.

The usual schedule for publishing the JOURNAL OF THE SCIENTIFIC LABORATORIES was maintained, *viz.*:

Vol. XXXIV, Articles 4 5, pp. 65–169, August, 1939
- New Ostracodes from the Menard Formation; Carey Croneis and Hubert M. Bristol. 38 pp., 2 plates.
- Pioneering in Yeneseiland. A Transect across Siberia from Mongolia to the Arctic; George B. Cressey. 67 pp., 51 figs.

Vol. XXXIV, Article 6, pp. 171 294, December, 1939
- New Crinoids from Upper Pennsylvanian and Lower Permian Rocks of Oklahoma, Kansas, and Nebraska; Raymond C. Moore. 109 pp., 39 figs., 5 plates.
- Report of the Permanent Secretary of the DENISON SCIENTIFIC ASSOCIATION. 8 pp.

Vol. XXXV, Articles 1–2, pp. 1–54, April, 1940
- The Relative Efficiency of Single Versus Multiple Exposures in the Rapid Memorization of Visual Forms; L. C. Steckle. 31 pp., 7 figs.
- New Genera of Pennsylvanian Crinoids from Kansas, Oklahoma, and Texas; Raymond C. Moore. 23 pp., 9 figs., 1 plate.

As was to be expected, the spread of war throughout the Eastern Hemisphere brought with it a curtailment of scientific activity and a lessening of publication; both are reflected in the number of journals received in exchange for our JOURNAL OF THE SCIENTIFIC LABORATORIES OF DENISON UNIVERSITY and by gift. At the same time it is worthy of note that often the same mail will bring journals from China and Japan, or from Germany and France, or from England and Italy. Receipts from Latin America, Australia, Canada, and Russia are about up to their usual volume.

Having been advised by the International Exchange Service of the Smithsonian Institution that it can not send printed matter to many of the belligerent nations as long as hostilities last, we have reserved for correspondents and exchange institutions in these countries copies of our own JOURNAL, in order that their files may be completed (?) when peace again returns.

Respectfully submitted,

W. C. EBAUGH, *Permanent Secretary and Editor*

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